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Annette Froehlich *Editor*

Space Resource Utilization: A View from an Emerging Space Faring Nation

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Executive Summary

This report speaks to the need for a regulatory framework with regard to space resource utilisation. In doing so, significant elements of the subject matter have been explored, taking into account the different phases of a space mission and the perspectives of various actors and participants in the space arena. In order to achieve these tasks, the report tackled the subject matter from a number of angles.

Firstly, an analysis of the current national and international governance frameworks was performed, with regard to resource extraction and utilisation in space. Becoming more tangible, the view of established and emerging space nations was analysed next, specifically with extraction and utilisation in mind and in light of the new US Commercial Space Launch Competitiveness Act (CSLCA) of 2015. Following this, potential regulatory options were considered with a view to developing practicable regulations. Finally, recommendations as to what South Africa's position on the matter should be were proposed.

The report begins with an overview of the topic: A number of resource-laden objects have been visited in the past, namely, comets and asteroids, with increasing success. To date there have been six successful sample return missions. A natural extension of this is the topic at hand: asteroid mining. To get to grips with the topic, the report looked at the reasons and motivations involved. Firstly, asteroids hold the promise of a solution towards sustainable development in terms of the sheer volume of minerals they could provide. Secondly, there's the potential opportunity to use them as in-orbit propellant replenishers. Certainly this new industry would revitalise the global economy and provide substantial incomes to the parties involved.

The report noted a slightly more robust yet nevertheless tentative picture emerging with regard to the governance frameworks surrounding space resource utilisation. There are a number of relevant international frameworks relevant here: Firstly, the United Nations (UN) has developed five multilateral treaties, which provide a framework for outer space activities, the main one being the Outer Space Treaty of 1967. Subsequent to this, four further treaties were adopted to elaborate on this treaty. The most recent of these, the Moon Treaty, is the most pertinent to resource extraction but interestingly is the least signed and ratified treaty – endorsed by none of the major space powers.

While many other international agreements have been reached regarding common resources (for instance, those around the Antarctic and the deep seabed), and even though these seem like potential analogues for outer space, no further progress has been made on the Outer Space Treaty with regard to resource utilisation in space.

The picture that emerges from an analysis of various national governance frameworks is not much different. South Africa's own Space Affairs Act, while committing to peaceful uses of outer space for the benefit of all humankind, goes into no other detail regarding space resource utilisation.

This is in stark contrast with the US CSLCA of 2015, a piece of national legislation which specifically addresses resource mining. While there has been marked debate around this act, it holds the dubious honour of being the first piece of tangible legislation to tackle the issue of space mining head on. This is not to say that no one else is considering it. Even some emerging space nations have realised the potential opportunities here, and organisations like Nigeria's NASRDA have mentioned the need for legislation around the exploitation of outer space. Indeed, we see this sentiment echoed in the developed space nations, with provisions being made for subsequent legislation, but no ink is, as of yet, on paper.

While legislation is not immediately forthcoming, the report nevertheless looked at the views of both established and emerging space nations in this regard. This was achieved by a brief analysis of various budgets allocated to space exploration – as space mining would be a subset thereto.

Predictably, the established space nations spend significantly more than the emerging ones. While there has been quite a bit of theoretical exploration of the concept of space mining amongst the established actors, this is far less of the case with the emerging participants. Space mining is of course a subset of general space activity, which is necessarily economically and politically driven. It was noted that socioeconomic uses of space dominate the emerging nations' agendas. Compounding this, indeed for all potential space resource actors, is the uncertainty as to the economic feasibility of the endeavour.

Asteroid mining, although clearly still in the development phase, will necessarily have certain consequences that will guide any future views and opinions on the topic. Exploring these considerations gives potential insight into how the activity might unfold.

An immediate benefit of asteroid mining from a social perspective is the positive impact it would have on terrestrial mining – specifically the health of miners. This even extends to the general public: mining has many deleterious effects on the environment, for instance, water, soil and air degradation.

Asteroid mining would not necessarily be free of these consequences, as the minerals would still (on the whole) need to be returned to Earth to be used, and this also raises questions of safety. While much has been written about spaceflight safety, there is next to nothing regarding space mining, including from potential space mining companies. However, there are certainly some safety regulations with regard to space activities in general that have been documented, and potentially these can be brought to bear.

The report also noted the need to consider safety in longer spans of time: the environmental impact space mining might have. As previously seen socially, a positive environmental impact would be the near cessation of terrestrial mining activities. Bringing an asteroid into Earth's orbit (such as is proposed) could have even worse consequences however. Any accident whereby the asteroid actually enters Earth's atmosphere could be catastrophic. On a smaller scale, returning the mined ore to the surface is equally problematic. However, should these resources be usable in-orbit, space technology could be constructed beyond the confines of Earth and potentially negate much of the environmental impact caused by launching and returning to Earth. Adopting a positive attitude with an emphasis on fostering environmental ethics is desirable here.

This isn't just about a mental attitude; the rewards of space mining are certainly tangible. Space mining, as a subset of space activities, is endemically inspiring and promotes gravitation towards STEM-based vocations, which has direct economic benefits, in terms of both financial and intellectual capital gains. The financial gains should not be understated either. While feasibility analysis is still ongoing, the rewards are potentially enormous.

A word of caution however: The South African economy is pointedly underwritten by terrestrial mining, being the largest platinum producer in the world. Asteroid mining could significantly disrupt this and negatively affect GDP. While this situation is certainly a long way off, planning for the future is critical to the long-term survival of the economy.

Mineral resources have disrupted economies before. Access to large pools of non-renewable (such as is the case on Earth) resources has seen countries ignore the negative impact (via resource dependency) on economic growth for short-term gains. This can have significant effects on the political arena, where tax systems (at the heart of a government's socioeconomic stability) would be severely disrupted leading to potential political disruption. Indeed, in developing countries, this non-renewable dependency has been at the heart of numerous civil wars (with significantly greater regularity than countries without these resources).

Should the USA, for example, gain access to a new, and potentially much larger, pool of mineral resources, economic (and therefore political) upheaval can be expected. South Africa would certainly feel the effects of this, such as a change in the oil price on countries like Venezuela.

A long-term view is therefore important, and at the fore is the need for practicable regulations for space resource extraction and utilisation. An analysis and overview of existing models, both national and international, to be used as analogues and potential springboards, is therefore pertinent.

A good starting point in regulating space activities might be the international space treaties and Moon Agreement. As treaties are based on international law, they tend to be written in broad language and as a result do not tend to very specific issues. While subsequent treaties might to some degree remedy this, many see the Moon Agreement as too restrictive in this regard. Given the current level of engagement of private industries in space activities, stipulations in this agreement to the extent of potential taxation and compulsory sharing of information make it undesirable commercially and have clearly acted as deterrents to ratification for countries wishing to bolster this sector.

Similar to the treaties model is one based on the common heritage of mankind, where the beneficiary of common resources is changed from states to all people (the Convention on the Law of the Sea is a good example here). This common heritage principle, which we see filters down to national legislation, also underpins part of the Outer Space Treaty, and to a lesser extent that of Antarctica, and is now a legally accepted term. This infiltration of principle into common practice ratified by states has a norm-creating effect that can potentially underpin subsequent doctrine.

Backing this up will necessarily entail authorisation and licensing, which will fall to states and non-governmental entities, in an international capacity. Any licensing model will follow extant legislation, but with a view to international obligations – liability will rest solely with states. True to this model, transfer of ownership of celestial bodies will not take place (via the principle of non-appropriation), but usufruct will be established for defined periods of time.

Even though this model specifically revolves around the common ownership of resources, penalties for contravening policies and principles will nevertheless need to be established. This is, however, not necessarily a stumbling block. However, a common criticism of this model which *is* potentially problematic is that it is restrictive of industrial development, which can have both practical and financial implications for states. For an international regulatory framework to be successful, it will require widespread acceptance – this will therefore entail compromise between public and private interests.

As some have said, it is out of the need for clarity around private interests that the US CSLCA was born. The efficacy of this regulatory framework as a potential fit for international use is however poor. Specifically, the Act speaks only to national concerns and almost entirely neglects international ones.

A similar yet more expansive model might be to use that of terrestrial mining regulations. Here the interest is on activities that fall within international scope – such as deep seabed mining. Such activities are however by and large regulated by national laws, with little to no international involvement (other than some environmental, safety and human rights considerations). The UN has however involved both private and public entities in talks to discuss environmental concerns, with the guidelines which emerged being adopted as industry standards. As stated earlier, a balance between public and private interests is important for success.

When translating these potential models into the space mining arena, it is important to consider the potential competing interests that might arise in the exploitation of near Earth asteroids. A successful model would need to firstly balance industrialised states vs those still developing. On the one hand, if private entities cannot obtain property rights over celestial bodies, the incentive to obtain private investments will be lacklustre. However, the common heritage model calls for the equitable distribution of benefits derived from the exploitation of common heritage sites. This can be potentially navigated with the establishment of an international authority (such as the Seabed Authority) to implement a royalty or profit sharing system.

We see a similar dichotomy between economic development and environmental safeguards: given the huge need for efficacy in propulsion methods, the door needs to be open for nuclear and radioisotope fuel cells, but this of course raises environmental concerns. Careful and consistent regulation will be required. But overly stringent regulation can be seen to stifle the free market, which is essential if space mining is going to be commercially successful. That said, huge influxes of rare or valuable commodities can have a severely destabilising effect on the global commodities market and would require intervention in order to prevent this. This can also be seen in terms of public interest vs commercial concerns.

However, it has been observed that the UN has shifted from adopting multilateral treaties to General Assembly declarations, the binding nature of which is still controversial. So here we have the issue of hard law vs soft law: to provide an adequate regulatory framework for space mining activities will require multi-faceted enforcement mechanisms right through the value chain and will further require widespread international adoption. However, as seen with previous common heritage regulatory proposals, restrictive laws fail to gain sufficient international traction, while soft law fails to adequately provide protection for developing states and sufficient clarity for the satisfaction of private commercial enterprises to confidently operate.

In addition to establishing an international regulatory framework, there are also practical implementation issues to consider, such as the structure, composition, functions and power of an international space mining authority. Membership to such an authority could be limited to space-faring nations, states that have made financial investment to the commercial activities of such authority, UN member states or all states. While limited access models have worked in the past (e.g. Antarctica), applied here there may be an undermining of the legal effectiveness of the objectives of such an international framework. Certainly disputes will erupt, and mechanisms will need to be set in place to deal with these, which could happen via the establishment of various relevant panels. However challenging to implement, it remains clear that the absence of a clear regulatory framework is in itself a barrier to further space mining activities.

When considering potential regulatory pathways related to space activities, most states regulate via a unified national space authority or a combination of various ones. States without extensive space industries may choose to pursue the latter approach, as it requires less start-up investment. Of consideration however is that the authority mandated with the regulation of space mining may not be in a position to conduct technical oversight over operations. There is also the issue of redundancy of operations.

A policy development pathway is therefore desirable. A clearly established path as to what needs to be achieved and what meaningful role the state might play, specifically within the context of strategic partnerships (in the case of South Africa, BRICS and SADC), will greatly facilitate the eventual regulatory process.

While the spirit of the Moon Treaty is important, it is this report's recommendation that South Africa does not ratify. There are a number of reasons for this. Firstly, South Africa's place in the global space arena is still uncertain, and restricting potential commercial opportunities (which is a common criticism of the Moon

Treaty) is undesirable. Secondly, South Africa is part of the BRICS partnership and needs to stay in line with these member states from a regulatory point of view.

That said, a proposed national regulatory framework should include the principles established in the Outer Space Treaty, those established in the 'Principles Relevant to the Use of Nuclear Power Sources; Declaration on International Cooperation in the Exploration and Use of Outer Space for the Benefit and in the Interest of All States, Taking into Particular Account the Needs of Developing Countries' and the spirit of the Moon Treaty.

As a way forward, South Africa needs to champion UN regulatory work on human rights, safety and environmental law (including that pertaining to space debris mitigation) and to ensure international trade is not significantly disrupted by an influx of extra-terrestrial resources which will adversely affect the local economy.

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Chapter 1
Introduction

Since the dawn of humanity, civilization has advanced through ongoing development and utilization of the Earth's natural resources. However, the rapidly expanding population is using up the nonrenewable resources at an alarming rate. A possible solution to this terrestrial conundrum can come from the most unlikely of places, outer space, in the form of extraterrestrial mining.

Developing countries that rely on these ever-dwindling terrestrial natural resources are, as a result, facing economic uncertainty, and while extraterrestrial mining may seem like a relief thereto, it may simultaneously cause economic instability should an influx of mineral resources occur.

Certain celestial bodies, such as asteroids, contain within them the potential to provide untold riches; the future oil fields of space. This poses a question as to how outer space activities should be regulated. To this end, there are several international treaties regulating the peaceful utilization and exploration of outer space. Space and its celestial bodies are seen as the common heritage of humankind, and not subject to appropriation.

Subsequent to the enactment of the treaties, the space sector has undergone rapid expansion, mainly as a result of the dynamic growth of the private sector. While the common heritage doctrine is important to preserve, it is currently at odds with the revitalization of industry.

In seeming response to industry, the United States enacted legislation with regards to commercially spurring its local space industry, specifically with regards to space mining. While this is US national legislation, the economic and legal implications are far reaching. With this in mind, South Africa needs to consider its options carefully. While being a developing space nation, our direct participation in the space mining arena is limited, we are nevertheless (via BRICS) partnered with significant space fairing nations.

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While the practical realization of space mining is still in its infancy, South Africa needs to be proactive in its involvement in the international space mining arena to avoid exclusion. This document serves to outlines the topic of space mining in the South African context.

Chapter 2
Overview

2.1 Background to Asteroids and Other Prospective Bodies

In order to mindfully extract, examine, and experiment on resources in space, it is important to first familiarize ourselves with past acquired research. Prior to 1991, our knowledge of asteroids was limited to telescope images and fragments that survived their fall to Earth. However, in 1991, NASA spacecraft, Galileo, flew by the asteroid Gaspra on its way to Jupiter and recorded 57 images from a distance of approximately 5300 km.[1]

This was followed by a steady stream of asteroid visits every 2–3 years. A total of 13 asteroids and 9 comets have been visited by unmanned space probes. All recorded visits were carried out for research purposes by various institutions and space agencies, which include a number of "fly-by" visits (Fig. 2.1 and Table 2.1).

To date samples of six identified solar system bodies have been collected. Celestial rocks make their way to Earth in one of two methods:

1. Naturally entering Earth's atmosphere due to some activity on parent body, e.g. collisions with smaller bodies resulting in cratering
2. Samples brought back from space missions

Thus far only the Apollo and Soviet Luna missions have collected moon rocks; however China may soon join, having successfully landed on the Moon in 2013 and recent discovery of a new type of moon rock in December 2015. Their scheduled sample return mission is set for 2017. During the six Apollo landing missions, 2415 samples weighing 380.96 kgs were collected. Three Luna spacecrafts returned with 326 grams of samples. Comet samples were retrieved from Wild 1's coma in 2006, and asteroid samples from Itokawa in 2010 as discussed above. Remaining samples were collected from meteorites and from Earth.

[1] NASA Jet Propulsion Laboratory, n.d., *Mission to Jupiter. Galileo*. Available at: http://www.jpl.nasa.gov/missions/galileo/ [Accessed May 22, 2017].

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https://doi.org/10.1007/978-3-319-66969-4_2

Fig. 2.1 Images of Eros (Courtesy of Jet Propulsion Laboratory – NASA, 2001)

Meanwhile, the exploration of small solar system bodies (such as asteroids, comets or irregular moons) has become a central objective for planetary exploration.[2]

Asteroids Asteroids are leftover primordial materials that were created from the formation of the solar system; many also contain enormous quantities of resources.

Studies have shown that the most desirable asteroids for mining or return are the carbonaceous C-type asteroids that contain a rich mixture of volatiles, complex organic molecules, dry rock and metals. They make up about 20% of the known population. Retrieving such asteroid material would enable the development of as many extraction processes as possible and can yield as much as 40% by mass of extractable volatiles, roughly equal parts water and carbon-bearing compounds.[3]

Orbits and Temperature Asteroids revolve around the Sun in elliptical orbits; they rotate, sometimes tumbling quite erratically. The average temperature of the surface of a typical asteroid is minus 73 °C.

Classifications of Asteroids Classifications of asteroids are broadly based on their orbit (dynamical classification) and their surface composition (spectral classification).

(a) Dynamical classification: This is based on which area of the solar system an asteroid is found; it can be classified into one of many groups and subgroups, e.g. NEOs, Asteroid Belt, Jupiter Trojans, Outer Solar System, trans-Neptunian objects, etc.

(b) Spectral classification (surface composition): Most asteroids fall into three classes based on composition. *The C-type or carbonaceous* (water, volatiles) are greyish in colour and are the most common, including more than 75% of known asteroids. *The S-type or silicaceous* asteroids (silicates, sulphides, metals) are greenish to reddish in colour, account for about 17% of known asteroids and dominate the inner asteroid belt. They appear to be made of silicate materials and nickel-iron. *The M-type (also X-type) or metallic asteroids* make up most of the *rest* of the asteroids and dwell in the middle region of the main belt.

[2] National Research Council, 2011, *Vision and Voyagers for Planetary Science in the Decade 2013–2022*. Available at http://solarsystem.nasa.gov/2013decadal [Accessed May 22, 2017].

[3] Lewis, J. S., 1996, *Mining the Sky: Untold Riches from the Asteroids, Comets, and Planets,* Helix Books, New York.

Table 2.1 Selection of celestial bodies visited by spacecrafts

Celestial body	Spacecraft and operator	Date/year visited	Additional information
Gaspra (asteroid)	Galileo – NASA (USA), Deutsches Zentrum für Luft- und Raumfahrt e.V. (Germany)	1991/10/29 (fly-by)	First asteroid visited by a spacecraft. Spectral type: S
Eros (asteroid) (see Appendix B)	NEAR Shoemaker – NASA, Applied Physics Laboratory (APL) (USA)	2001/01/12	First near-Earth asteroid orbited by a spacecraft and the first asteroid landing. Spectral type: S
Wild 2 (comet)	Stardust – NASA, Jet Propulsion Laboratory (JPL), University of Washington (USA)	2004/01/02 (fly-by)	First samples collected from a comet's coma and returned to Earth
Itokawa (asteroid)	Hayabusa – JAXA (Japan)	2005–2010	First sample return mission from an asteroid. Spectral type: S
Tempel 1 (comet)	Deep Impact – NASA, JPL, University of Maryland (USA)	2015/07/04	Comet deliberately struck by Deep Impact Probe[a]
Churyumov–Gerasimenko (comet)	Rosetta – ESA (Europe)	2014/05/12–presentb	Orbit was entered in September. First spacecraft to land on comet nucleus. Lander landed on 12 November 2014
Ceres (asteroid)	Dawn – NASA (USA)	2015/03/06–present	First asteroid observed as spacecraft orbits the body

NASA Jet Propulsion Laboratory, n.d., Missions. Available at:http://www.jpl.nasa.gov/missions/ [Accessed May 22, 2017]

[a]Tempel 1 was deliberately struck by the probe at a relative speed of 37,000 km/h. Ice debris was produced and a crater formed on the comet surface, observed by the spacecraft days after collision. The energy from collision can be compared to five tons of dynamite. Mission received positive and negative reviews. NASA deemed it as a success (NASA, n.d., *Deep Impact Mission to a comet*. Available at: http://www.nasa.gov/mission_pages/deepimpact/main/#.Vue0BpN97Vo [Accessed May 22, 2017]). Following the collision, China emerged with news of their research into a "more clever" method called "pasting", whereby a spacecraft with engine capacity would soft-land on a celestial body and then slowly push that body off course, should the body be heading for possible collision (The Economic Times, 2005, *After US, China plans 'Deep Impact' mission*. Available at: http://archive.li/9E2QY [Accessed May 22, 2017]).

[b]Rosetta lander, Philae, entered safe mode on 15 November 2014. Equipped with solar panels, the lander could reboot if sufficient sunlight received.

Comets Ice mixed with small amounts of rock debris, dust, and organic matter from deep within the solar system. Most comets travel around the Sun in highly elliptical orbits that carry them a thousand times farther out into space than the planets (Table 2.2).

Table 2.2 Comparison between the Moon and asteroids

Moon vs the asteroids		
Moon		Asteroids
Composition	The Moon is better understood in terms of mineralogy – Apollo heritage	Few visits by spacecraft we don't know much at all about the composition of target asteroids near Earth
Ore quality	Few parts per million (ppm) in lunar regolith	High-grade ores
Fuel budget	Requires fuel for landing and take-off, which means a larger payload launched from Earth	Does not require huge delta-v for landing and take-off, electric propulsion applicable
Transit period/ emergency	Moon always few days away	Few windows of opportunity for encounter and could take months
Teleoperation	Communications time delay of just 2 seconds	Minutes for some (near-Earth asteroids) NEAs
Gravity well	1/6th of Earth's gravity	Asteroids offer zero gravity and microgravity materials processing options

Generally, the lunar surface is volatile poor and metal poor comparable to slag discarded in metallurgical processing on Earth.[4]

Phobos and Deimos Small moons of Mars; scientists believe they were captured bodies from the nearby main asteroid belt. Both are oblong chunks of rock in nearly circular orbits around Mars. Their proximity to Mars makes them good resources mining candidates possibly for shielding material and rocket fuel.[5] They could also serve as an outpost during Mars exploration. The only downside is the high delta-v required for return to LEO.[6]

Launch, Orbital Mechanics and Trajectory Design Considerations
Constraints for launch and return dates will have far-reaching implications to mining operations Trade-offs may be required for potential destinations. A round trip mission to any target may be routed through several destinations: directly to Earth, to a midpoint station such as a Lagrangian point, geosynchronous orbit, the surface of the Moon, Phobos or Mars. In the future, these midpoints could further be developed as supply stations for various prospecting and mining missions.

Mission Design and Operations and Astrodynamics
In a situation where the monitoring of activities on the surface requires real-time or direct teleoperations, then a human crew should be on site to coordinate activities.

[4] Lewis, 1996, *Mining the Sky: Untold Riches from the Asteroids, Comets, and Planets*.

[5] Matloff, G.L., & Wilga, M., 2010, *NEOs as stepping stones to Mars and main-belt asteroids*, Acta Astronautica, 68(5–6), 599–602.

[6] Ross, M., Mills, M. & Toohey, D., 2010, *Potential climate impact of black carbon emitted by rockets*, Geophysical Research Letters, 37(24), 1–6.

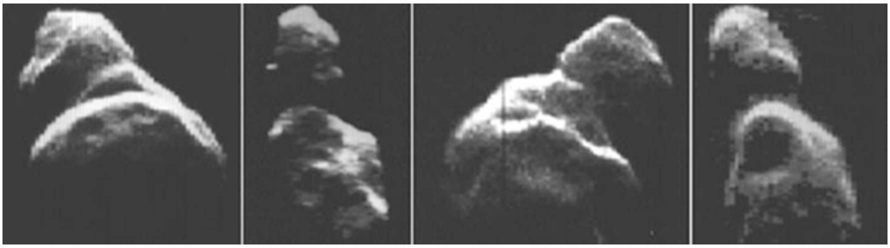

Fig. 2.2 Four radar images of asteroid 4179 Toutatis created by the Goldstone DSN antennas (NASA/GSFC)

The presence of robotic spacecraft and/or humans in the mining operation calls for different mission design and operation procedure.

Optimal trajectories and propulsion are required to go and return from missions. It has been estimated that about 10% of all NEAs are more accessible than the Moon in terms of delta-v requirements and are very much easier to return to Earth from than the Moon.[7]

The Use of Radar in Asteroid Studies

One of the tools used to study asteroids is radar (radio detection and ranging). With adequate orientational coverage, such images can be used to generate detailed 3D models, define the rotation state precisely and constrain the object's internal density distribution.

Radar systems have transmitters which emit radio waves called radar signals in predetermined directions towards target object(s). If the object is moving either towards or away from the transmitter, as in the case of an asteroid, there is a slight corresponding change in the frequency of the radio waves, caused by the Doppler Effect. These characteristics provide a powerful source of information about the physical properties and orbits of asteroids. Measurements of the distribution of echo power in time delay give the distance, while Doppler frequency gives radial velocity of the asteroid. The data from the receiver produce two-dimensional images that can provide spatial resolution as fine as a decametre with strong echoes (Fig. 2.2).

2.2 Reasons and Motivation for Asteroid Mining

With the current development of asteroid mining technology, it is necessary to analyse the consequences it could carry. In this section the potential benefits of asteroid mining are presented from an environmental, economic and, industrial point of view.

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[7] Lewis, J. S., 1993, *Logistical Implications of Water Extraction from Near-Earth Asteroids,* Princeton Conference on Space Manufacturing, Space Studies Institute, Mojave.

Technology is evolving at exceptional rates, in addition to an exponential population growth, and its demand of limited natural resources. This is inducing some effects that must be addressed. On the one hand, the increasing need of resources is driving to their depletion. On the other, the current obtainment techniques are damaging the environment on our planet. These techniques include mining or burning of dirty coal and fossil fuels, oil and gas extraction from the ocean, and deep seabed or the environmentally destructive rare-Earth mineral mining promoted mainly by the development of the electronics sector. Some of their consequences are the climate change, contamination of water and the pollution of the atmosphere and the environment.

Asteroids' mining could be a solution to reach sustainable development, as they could become the main sources of some metals and other materials. Thus, it would preserve Earth's environment and allow humankind to maintain or improve their standard of living.[8]

From a technological point of view, asteroid mining could entail the following advancements: Firstly, as proposed by Planetary Resources, it could serve to cover larger distances in space by supplying propellant in orbit. In concrete, they intend to obtain hydrogen and oxygen through the electrolysis of water, present in the asteroids (Planetary Resources n.d.). Secondly, there are big quantities of some metals and rare-Earth materials in the asteroids, such as platinum, that because of their scarcity are expensive on Earth. Asteroid mining would then make it cheaper and so contribute to the development of certain technologies, such as electronics.[9] Thirdly, it would permit the production of high-value and material purity goods, such as pharmaceuticals, semiconductors, or ultra-pure crystals. It would also boost the space tourism market by allowing the construction in orbit of structural materials, solar photovoltaic arrays, shielding against radiation from unprocessed mass and orbital hotels.[10]

Economically, NEA mining could have significant benefits. First of all, it would impulse the economy through the establishment of a new industry and generation of new job opportunities. Also, their harvesting would carry substantial incomes for commercial companies, withal the cost of developing the required technology and the whole mission. For instance, fragments of the asteroid Chelyabinsk, which crossed Earth's atmosphere over Russia on 15 February 2013, have been sold for prizes up to US $10,000 to American laboratories.[11]

Nevertheless, it is important to bear in mind that space mining could also cause undesired counter effects, such as back contamination, adverse changes in celestial

[8] Hlimi, T., 2015, *The Next Frontier: An Overview of the Legal and Environmental Implications of Near-Earth Asteroid Mining*, Annals of Air and Space Law, 39, 409–53.

[9] Blair, B.R., 2000, *The Role of Near-Earth Asteroids in Long-Term Platinum Supply*, Colorado School of Mines, Golden.

[10] \Ross, Mills, & Toohey, 2010, *Potential climate impact of black carbon emitted by rockets*.

[11] Hlimi, 2015, *The Next Frontier: An Overview of the Legal and Environmental Implications of Near-Earth Asteroid Mining*.

bodies' environments or an increase in the space debris in the Earth's orbit.[12] Thus, although mining could trigger substantial benefits for humankind and the Earth, it must be done responsibly and safely. It is essential to adapt the international regulatory framework for space mining to the new technologies and opportunities.

2.3 Space Mining Methods

Space mining begins with prospecting, which is the process of discovering and analysing mineral deposits. In space this process has already begun using telescopes and monitoring stations on Earth. Companies have proposed sending small reconnaissance satellites equipped with spectral analysers to determine composition. Once this cataloguing process is complete, we will need to launch small sample return missions to verify the existence of these mineral deposits, and only then can large-scale mining missions begin.[13,14]

The mining process in space however has its own challenges which we will need to overcome. The lack of gravity might be seen as a benefit, but without its presence to bring excavation tools and excavated material to a standstill, they could float around haphazardly, either drifting away or colliding with other equipment. Dust and tiny fragments generated during mining activities also present the potential issues of obscuring vision and clogging machinery. Furthermore, resources and ore removed from an asteroid can result in a momentum change which alters its trajectory. To combat these situations, effective measures would need to be put in place.[15,16]

Two concepts that are integral to any proposed excavation or extraction method are that of anchoring and bagging. Anchoring is a method by which apparatus is held to an asteroid body by some type of attachment; examples include cables, clamps, tethers and hooks, thus preventing the free movement of equipment. Bagging is where the entire asteroid or part of its surface is covered in an enclosure such as a capsule or non-permeable bag. The bag being fixed to the asteroid prevents material from drifting away and preserves the change in momentum. Dust however remains trapped in the bag where it can still affect the other tools and thus would need to be compensated for using suitable methods.[17]

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[12] Hlimi, 2015, *The Next Frontier: An Overview of the Legal and Environmental Implications of Near-Earth Asteroid Mining*

[13] Deep Space Industries, 2016, *Prospecting*. Available at: https://deepspaceindustries.com/mining/ [Accessed May 23, 2017].

[14] Cohen, M.M., 2013, *Robotic Asteroid Prospector (RAP). Staged from L1: Start of the Deep Space Economy*. Available at: https://www.nasa.gov/sites/default/files/files/Cohen_2012_PhI_RAP.pdf [Accessed May 18, 2017].

[15] Gertsch, R.E., 1992, *Asteroid mining*, in: McKay, M.F., McKay, D.S., & Duke, M.B. (eds.), Space Resources, Lyndon B. Johnson Space Center, Houston, 111–120.

[16] Gertsch, R., Remo, J.L. & Gertsch, L.S., 1997, *Near-Earth resources*, Annals of the New York Academy of Sciences, 822, 468–510.

[17] Gertsch, Remo, & Gertsch, 1997, *Near-Earth resources*.

These are some proposed extraction and collection methods which incorporate bagging and/or anchoring techniques and can be used as a baseline for further discussion:

Fragmentation: is the mechanical process of breaking down the asteroid into smaller parts or fragments. This includes drilling, cutting, auguring, shears and scoops.[18,19]

Rubblization: is similar to fragmentation but uses blasting material to perform the separation.[20]

Magnetic systems: can be used to lift and collect fine metallic regolith and dust particles.[21]

Pneumatic systems: uses gas techniques to blow and collect tiny fragments, powders and dust particles.[22]

Redirection: is a method in which the orbit of an asteroid or part thereof is altered in some way to move it closer to Earth or to a point where further mining practices can take place. Examples are the use of thrusters to lift and move an object[23] or the concept of mass wasting in which controlled blasts are used to eject material from the asteroid causing a momentum reaction which alters its course.[24]

2.4 Space Mining Extraction and Processing Methods

Asteroid mining is in its infancy, and therefore there has been very little development or research conducted into extraction and processing methods or technology.[25] The details of the extraction or benefaction processes will be easier to determine when one knows what would be the profit from the ore. Will the ore be brought back to Earth and then sold or will it be sold and delivered to orbit - and will the non-valuable remains be brought back to the operator for process enablement?

[18] Gertsch, 1992, *Asteroid mining*.

[19] Gertsch, Remo, & Gertsch, 1997, *Near-Earth resources*.

[20] Gertsch, Remo, & Gertsch, 1997, *Near-Earth resources*.

[21] Blair, 2000, *The Role of Near-Earth Asteroids in Long-Term Platinum Supply*.

[22] Cohen, 2013, *Robotic asteroid prospector (RAP) staged from L1: start of the deep space economy.*

[23] Wilson, J., 2015, *What Is NASA's Asteroid Redirect Mission?* Available at: https://www.nasa.gov/content/what-is-nasa-s-asteroid-redirect-mission [Accessed April 6, 2017].

[24] Gertsch, Remo, & Gertsch, 1997, *Near-Earth resources*.

[25] Cohen, 2013, *Robotic asteroid prospector (RAP) staged from L1: start of the deep space economy.*

Another complication with developing extraction and processing technology is that as there is no definite way of knowing in what quantities the desired ore will be recovered or what impurities exist in the gangue.[26,27]

Two broad options are currently discussed with regard to processing the mined material. The first option is to process and separate the ore so that the tailings can be discarded at the asteroid, reducing the return mass but requiring a processing plant at the asteroid. Alternatively, the raw ore material from the asteroid can be loaded, and some of the material can be processed during the return flight to produce in situ propellant, while the rest is processed in an Earth orbit processing plant.[28,29,30]

In situ propellant production is a possibility as the return from the asteroid does not require constant lift which reduces the demand on the propulsion and power system and it uses less Δ v required than the lift mass to LEO. Volatiles (O_2, H_2, hydrocarbons and ammonia) need to be mined and processed on-board the spacecraft to produce the propellant. In situ propellant would also allow for the asteroid material to slow down for Earth capture by using aerobraking or propulsive braking systems.[31,32]

The processing of materials, in general, can be broken down into the following main categories:

Water extraction: water can be used for fuel or solar thermal propulsion, but it is also required for various mining processes and is a very energy-intensive operation. This can be done in two ways: the first is an asteroid with ice that can be placed in a bag and heated directly from the Sun using solar concentrators. Alternatively, regolith that contains ice can be captured using a deep auger flute; however this method has a lot more steps and is more complicated.[33]

Metals: Developing any metallurgical process is highly complex and currently not a feasible aspect in the space environment; however potential new approaches may include plasma heating and vapour deposition/selective condensation of various elements.[34,35]

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[26] Sonter, M. J., 1996, *The Technical and Economic Feasibility of Mining the Near-Earth Asteroids,* MSc thesis, Dept. of Physics and Dept. of Civil and Mining Engineering, University of Wollongong.

[27] Cohen, 2013, *Robotic asteroid prospector (RAP) staged from L1: start of the deep space economy.*

[28] Sonter, 1996, *The technical and economic feasibility of mining the near-Earth asteroids*.

[29] Ross, S.D., 2001, *Near-Earth Asteroid Mining*. Available at: http://www2.esm.vt.edu/~sdross/papers/ross-asteroid-mining-2001.pdf [Accessed March 15, 2016].

[30] Gertsch, Remo, & Gertsch, 1997, *Near-Earth resources*.

[31] Sonter, 1996, *The technical and economic feasibility of mining the near-Earth asteroids*.

[32] Ross, 2001, *Near-Earth Asteroid Mining*.

[33] Cohen, 2013, *Robotic asteroid prospector (RAP) staged from L1: start of the deep space economy.*

[34] Cohen, 2013, *Robotic asteroid prospector (RAP) staged from L1: start of the deep space economy.*

[35] Sonter, 1996, *The technical and economic feasibility of mining the near-Earth asteroids*.

Volatiles and hydrocarbons: These processes would likely require some form of vapour processing that requires a generating and recycling of a carrier gas for heating and volatilization, collection of gas and entrained solids, separation of entrained solids, condensation of vapours collectively or separately and intensive heating/cooling requirements.[36]

In situ *extraction*: Processing of the materials at the asteroid. It requires less mass to be transported when compared to other methods, but requires a filtration process, pressurization of equipment and reheating/heat exchange processes for the drilling and heating of fluids.[37,38]

The processing needs to take place in zero gravity, the materials are poorly defined and chemically heterogeneous and possibly mutually reactive when heated and special attention needs to be made for the generation of make-up fluids, and heat processing for volatile recoveries is just one of the challenges that haven't been broached by technology yet.[39]

In conclusion, processing designs are practically non-existent and shall remain so until it is known where the plant will be built (on Earth, in Earth orbit or on the asteroid). It also is impossible and unfeasible to design the process prior to knowing to what extent the ore needs to be processed and for what use (they are related). Terrestrial mining operations centre around the main mineral product; there is no "universal mining toolkit' that can extract and process any and all ores from an asteroid.[40]

[36] Sonter, 1996, *The technical and economic feasibility of mining the near-Earth asteroids*.

[37] Sonter, 1996, *The technical and economic feasibility of mining the near-Earth asteroids*.

[38] Ross, 2001, *Near-Earth Asteroid Mining*.

[39] Sonter, 1996, *The technical and economic feasibility of mining the near-Earth asteroids*.

[40] Cohen, 2013, *Robotic asteroid prospector (RAP) staged from L1: start of the deep space economy.*

Chapter 3
Analysis of the Current International and National Governance Framework as Pertaining to Resource Extraction and Utilisation in Space

3.1 International Frameworks Relevant to Space Resource Extraction and Utilisation

3.1.1 UN Space Treaties Binding, Including the Five Major Space Treaties

The United Nations has developed five general multilateral treaties, which provide a basic framework for activities in outer space. The first is the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, which entered into force in 1967. Following this, four more treaties were adopted to elaborate on the text contained in the Outer Space Treaty:

1. Agreement on the Rescue of Astronauts, the Return of Astronauts and the Return of Objects Launched into Outer Space, entered into force on 3 December 1968 (Rescue Agreement);
2. Convention on International Liability for Damage Caused by Space Objects, entered into force on 1 September 1972 (Liability Convention);
3. Convention on Registration of Objects Launched into Outer Space, entered into force on 15 September 1976 (Registration Convention);
4. Agreement Governing the Activities of States on the Moon and Other Celestial Bodies, entered into force on 11 July 1984 (Moon Agreement).

The most pertinent of these to resource extraction is the Moon Agreement, which was opened for signatures in 1979 but only entered into force in 1984. It is considered by some to be a failed treaty as none of the main space powers including Russia, the United States, China, Japan and India have ratified it,[1] although it is

[1] Coffey, S., 2009, *Establishing a Legal Framework for Property Rights to Natural Resources in Outer Space,* Case Western Reserve Journal of International Law, 41(1), 119-47.

A. Froehlich (ed.), *Space Resource Utilization: A View from an Emerging Space Faring Nation*, Studies in Space Policy 12,
https://doi.org/10.1007/978-3-319-66969-4_3

noted that resource extraction must be carried out in accordance with international conventions on safety, liability and registration of space objects, as it states in the Outer Space Treaty, which most states have ratified.

As the launching state, states parties to the treaties are liable for damage caused by their space objects. This includes private companies, as states bear the international responsibility for the activities of its citizens and nongovernmental entities under its jurisdiction. Although there is no requirement for it, in Resolution 68/74, the UN General Assembly recommends that states introduce insurance requirements for space activities operating within their jurisdiction.

There is also a requirement for all space objects to be registered with a registry maintained by the launching state. Further to this, onus is on the state to inform the secretary-general of the United Nations of items on the registry. The content of the registry, which is maintained on a national level, is decided by the state, with consideration of the reporting requirements of state to the UN, which include the (a) name of launching state, (b) registration number, (c) date and location of launch, (d) basic orbital parameters and (e) general function of the space object.

With regard to the activity of resource extraction, the resources in the Moon Agreement are considered the province of all mankind, and as such the benefit of extracting such resources should be in the interest of all countries regardless of their economic or social development. Expanding on this, Article 11 of the Moon Agreement deems the moon and other celestial bodies' resources as being the common heritage of mankind. In accordance with the Outer Space Treaty and international conventions, the Moon Agreement sets forth the formation of an international regulatory body to govern the moon and other celestial bodies. The main purpose of this governing entity is to maintain the (a) safe and efficient use of the moon's resources, (b) management of those resources, (c) expansion of opportunities in those resources and (d) equitable sharing by all states parties in the benefits derived from those resources considering economic and social aspects of developing countries and the efforts of the states extracting the resources.[2,3]

The states parties will be required to inform the secretary-general of the United Nations as well as the public and scientific community regarding their space activities in order to manage the time and resources. Information required would include the time, locations, orbital parameters and duration of activities.[4] The Moon Agreement allows the right to collect and remove resources as required for the mission, and the extracted resources will be at that states' disposal. States are required

[2] United Nations Office for Outer Space Affairs, 2008, *United Nations Treaties and Principles on Outer Space and related General Assembly resolutions*. Available at: http://www.unoosa.org/res/oosadoc/data/documents/2008/stspace/stspace11rev_2_0_html/st_space_11rev2E.pdf [Accessed May 22, 2017].

[3] United Nations, 1967, *Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies,* United Nations, New York.

[4] United Nations, 1967, *Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies.*

to extract the resources in such a way as not to disturb the environment or introduce additional safety risks.[5]

There is no process in place for designation of research and extraction areas, as parties are only required to inform each other and the UN of proposed activities. The Moon Agreement does not make provision for addressing conflicts between states operating simultaneously in the same area, requiring only that the "party promptly inform the other State of the timing of and plans for its own operations".[6] There is also no contingency for disciplinary action in the event states parties do not adhere to the conditions of the agreement.

3.1.2 UN Space Resolutions and Principles (Nonbinding), Including Those Found in UN COPUOS and UNGA

Space exploration activities and uses thereof are regulated by norms and rules derived from general principles of international law including some principles that were developed out of unique experience in outer space.[7]

3.1.2.1 United Nations General Assembly

The United Nations ("UN") plays a key role in facilitating development of independent international governance frameworks on space activities by member states. In order to fulfil this role, which includes monitoring space activities, the United Nations General Assembly ("UNGA") has created a number of committees including the United Nations Committee on Peaceful Uses of Outer Space ("COPUOS") with specific mandates.[8]

The COPUOS is the forum for the development of laws and principles governing outer space activities by member states. The Office of Outer Space Affairs ("OOSA") is the secretariat of COPUOS.

Further, COPUOS executes its mandate through two subcommittees, namely, the Scientific and Technical and Legal subcommittees. Decisions of the COPUOS subcommittees are taken based on consensus among committee members.

COPUOS in its historic deliberations reached consensus on a variety of treaties and agreements including those described above as binding treaties.

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[5] United Nations, 1967, *Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies.*

[6] United Nations Office for Outer Space Affairs, 2008, *United Nations Treaties and Principles on Outer Space and related General Assembly resolutions*.

[7] Christol, C.Q., 1991, *Space Law: Past, Present and Future*, Kluwer, Deventer.

[8] Martinez, P., 2013, *Role of COPUOS in promoting sustainability of outer space activities*, UNIDIR Space Security Conference, 2013.

3.1.2.2 UN Legal Outer Space Regimes

The UN has facilitated for regimes that allow for the uses of outer space for the benefit and interests of all countries, irrespective of a country's development status or involvement in space activities.[9,10] The regimes developed and adopted through facilitation of the United Nations include:

- Freedom of exploration and use of outer space[11]
- No territory sovereignty in outer space on celestial bodies
- Space activities conducted in accordance with international law
- Peaceful use of outer space activity
- Sovereign rights of states on objects launched into outer space
- International liability of states for their national space activities
- Avoidance of harmful effect of experiments in outer space
- Assistance for the astronauts in the event of accident and distress or emergency landing
- Promotion of international cooperation in exploration and use of outer space

3.1.2.3 Further Agreements

Under the auspices of the United Nations, states entered into further agreements in the use of outer space for telecommunication and other purposes. The United Nations tasked the International Telecommunications Union (ITU) to manage the GEO belt for purposes of preventing physical and electromagnetic interference. Consequently ITU is responsible for assignment of GEO slots to member states.

3.1.2.4 UN Legal Principles on Outer Space

The United Nations legal principles on outer space are nonbinding. Vladimir Kopal[12] argues on adoption of "1963 Declaration of Legal Principles" that *almost all of the fundamental principles of space law of our times originated in this Declaration and they still provide a succinct picture of the general nature and content of this new branch of international law.* The 1963 Declaration included a set of general

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[9] United Nations, 1967*, Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies,* Article I.

[10] United Nations, 1996, *Declaration on international cooperation in the exploration and use of outer space for the benefit and in the interest of all States, taking into account needs of Developing Countries*, United Nations, New York.

[11] United Nations, 1963, *Declaration of Legal Principles Governing the Activities of States in the Exploration and Use of Outer Space,* United Nations, New York.

[12] Kopal, V., 1998, *The role of United Nations Declarations of Principles in the Progressive Development of Space Law*, Journal of Space Law, 16(1), 5-20.

principles which characterised the legal status of outer space and celestial bodies and outlined the scope of legality for activities of states in the space environment.

On the heels of the Declaration, the COPUOS developed the following legal principles on outer space activities:

- Declaration of legal principles governing the activities of states in exploration and use of outer space (1963).
- Principles governing the use by state of artificial Earth satellites for International Direct Television Broadcasting (1982).
- Principles relating to remote sensing of Earth from outer space (1986). This principle provides for international law on the acquisition, dissemination and use of remote outer space sensed data.
- Principles relevant to the use of nuclear power sources in outer space (1992).
- Declaration on international cooperation in exploration and use of outer space for the benefit and in the interest of all states, taking into account particular account the needs of Developing Countries (1996).

3.1.2.5 Norms Development in Outer Space

The author(s)[13] define that norms of behaviour can be described as voluntary "rules of the road" that can set baseline standards of conduct intended to mitigate threats to safety, security, and stability in outer space. The adoption of the Outer Space Treaty marked the beginning of a period that saw a significant amount of political will aimed at the adoption of formal legal instruments.[14]

3.1.2.6 UN Resolutions on Outer Space

Under the auspices of the United Nations, a number of resolutions related to outer space activities were adopted by the UN General Assembly. Keys among these resolutions are the following:

- Resolutions 1721 A and B (XVI) of 20/12/1961 on COPUOS to study and report on legal issues related to use of outer space
- Resolution 55/122 of 8/12/2000 at paragraph 4 on some aspects concerning the use of the geostationary orbit
- Resolution 59/115 of 10/12/2004 on application of the concept of "Launching State"

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[13] United Nations Institute of Disarmament Research, 2013, *A Brief Overview of Norms Development in Outer Space*. Available at: http://www.unidir.ch/files/publications/pdfs/a-brief-overview-of-norms-development-in-outer-space-en-462.pdf [Accessed May 22, 2017].

[14] Kopal, 1998, *The role of United Nations Declarations of Principles in the Progressive Development of Space Law*.

- Resolution 62/101 of 17/12/2007 on the practice of states and international intergovernmental organisation in registering space objects
- Resolution 62/217 of 22/12/2007 on endorsement of the space debris mitigation guidelines of COPUOS
- Resolution 64/86 of 10/12/2009 on safety framework for NPS applications in outer space by the COPUOS.

3.1.2.7 Inter-Agency Space Debris Coordination Committee

In 2007 the Inter-Agency Space Debris Coordination Committee ("IADC") published a set of voluntary guidelines designed to reduce the creation of orbital debris. These guidelines included:

- Limiting production of debris during routine operations.
- Minimisation of potential for accidents during on-orbit breakups.
- Disposal of spacecraft post-mission.
- Prevention of on-orbit collisions.
- Prohibition of intentional destruction of satellites.
- In 2008, a resolution on these guidelines was proposed by COPUOS and adopted by UNGA.

International space law contains several obligations and rights of states participating in outer space activities. The roles, responsibilities and liabilities of a launching state have been defined. This has heralded a new phase in outer space exploration, that is, commercialisation of outer space activities.

3.1.3 Relevant Resource Management and Common Heritage Treaties, Including Those on the Deep Seabed and Antarctica

Scott Ervin[15] advances the view that while space activity has increased, the world community has had increasing difficulty agreeing on specific rules of conduct to govern space use. Existing space law is based on broad theoretical principles contained in the first international agreement governing space use sponsored by the United Nations. These broad principles were sufficient to guide space use during the formative years of the space age, but as space activity has flourished, space law has lagged behind. Specifically, states attempting to formulate rules to govern specific space activities have not agreed on the meaning of space law principles.

[15] Ervin, S., 1984, *Law in a Vacuum: The Common Heritage Doctrine in Outer Space Law*, Boston College International and Comparative Law Review, 7(2), 403-31.

According to Herber,[16] the resources of outer space, the deep seabed (ocean floor) and the continent of Antarctica have been selected as the primary targets for application of the common heritage doctrine. The common heritage principle constitutes an alternative for determining property rights among nations. The latter postulates that land and natural resources belong to no nation until such activities as discovery, exploration and occupancy establish a widely recognised national sovereignty over them.

Having gone through the various governance frameworks and international agreements pertaining to areas of common heritage principle, the signatory countries have to subscribe to the promotion of the peaceful use of said areas and of course the common benefit that should be for all mankind.

As a country, South Africa would do well to strive to be one of the pathfinder countries and those who assist the development of frameworks for the seemingly inevitable space resource utilisation. There seems to be a prevailing stance by most countries to "keep their options open" by not signing and/or ratifying the Moon Agreement in particular.

In the context of other treaties such as in the United Nations Office for Disarmament Affairs, there is prohibition of the emplacement of nuclear weapons and other weapons of mass destruction on the seabed and ocean floor and subsoil thereof. There is strict exclusion of the above-mentioned in the arms race. The same prohibition exists for the Antarctic continent and for outer space though military personnel and equipment may be used for peaceful purposes.

It is noteworthy that there is no explicit prohibition on nuclear power or energy sources but instead there comes into play the liability of states parties should any incident occur either by governmental or nongovernmental entities. The treaty on principles governing the activities of states in the exploration and use of outer space, including the moon and other celestial bodies, states that states shall bear international responsibility for national activities in outer space, including the moon and other celestial bodies, whether such activities are carried out by governmental agencies or nongovernmental entities.

All countries, signers of the Outer Space Treaty of 1967,[17] fully embrace the principle that states are ultimately liable, and in the national laws, clear mention of private sector authorization, regulation and consequences for failures/transgressions is made.

States, and in particular South Africa, should be more active in the various fora to ensure that there is facilitation of the resource utilisation era, to avoid a disorderly "free for all" scenario and of course to be able to share insights since the nation is a mining leader. First point of contribution to the discourse would be redefining what exploration and use of space mean in detail. It is known that in the mining sector,

[16] Herber, B., 1991, *Mining or World Park? A Politico-economic Analysis of Alternative Land Use Regimes in Antarctica*, Natural Resources Journal, 31(4), 839-57.

[17] Secretariat of the Antarctic Treaty, 1959, *The Antarctic Treaty*. Available at: http://www.ats.aq/documents/ats/treaty_original.pdf [Accessed May 22, 2017].

exploration can include the sampling, testing and quantification of prospective resources even before actual formal resource extraction can be decided upon.

It is also a well-known industry fact that resource utilisation-driven activities may entail explosive work and/or blasting and that may be at odds with the treaty articles pertaining to prohibition of weapons being placed in orbit of or on celestial bodies, moon included. In light of private individuals and entities, such as SpaceX founder Elon Musk,[18] having suggested the use of nuclear explosions to alter Mars to possibly have it being more habitable is an example of the need to interrogate the prohibition and whether it must be worked on or left at status quo. The mere introduction of such considerations in mainstream debates has taken the issue out of the diplomatic realm of the United Nations meetings, but coupled with developments like the US CSLCA, there is evidently more need to discuss private entity space activities and the scope thereof. Ensuring there are adequate and robust frameworks in response to that is a role to be played.

The greatest difference is that Antarctica is a finite area, with determinable valuation prospects of resource exploitation, but in space the prospects are vast and too significant for states to simply declare and stick with a "no-go" position. The true main limitations have been centred around information, technology and overall economic viability. States, and South Africa in particular, should be seen to be responsive to changing economic and political climates, and space activities straddle those two domains.

International customary law is put to the test from time to time and similarly to the current situation, the deep seabed mining under customary international law, offers some insights. Excerpts of this law are included below:

> The declaration of principles affirms the existence of an international area free from state sovereignty, which cannot be subject to appropriation by any means by states or private persons. This area constitutes the common heritage of mankind, and its resources must be exploited for the benefit of mankind as a whole, and in particular of developing countries.[19]

South Africa can and should play a role in sharing experience, best practice and innovative ways drawn from dealing with mining and resource rights, related tax system and frameworks especially in line with the already existent UN launching state liability, authorisation and monitoring responsibilities. The country should be at the forefront with those progressive countries that can recommend commercial models for consideration and adaptation, as a start.

Environmental implications of resource utilisation are usually vast and long-lived, especially if they are not given the seriousness they deserve in consideration. Being a country grappling with historic and current problems of adverse mining practices such as acid mine drainage, landscape degradation, and various forms of

[18] Grush, L., 2015, *Elon Musk elaborates on his proposal to nuke Mars,* The Verge. Available at: https://www.theverge.com/2015/10/2/9441029/elon-musk-mars-nuclear-bomb-colbert-interview-explained [Accessed May 22, 2017].

[19] United Nations, 1970, *Declaration of Principles Governing the Seabed and Ocean Floor, and the Subsoil Thereof, beyond the Limits of National Jurisdiction*, United Nations, New York.

pollution and contamination, South Africa stands a great chance of shaping proactively, rather than reactively, the moving forward of celestial body resource utilisation, including the moon, learning from past shortcomings and innovating to meet future challenges and mitigating those unavoidable ones the best way possible. Article IX of the Moon Agreement, as described previously above, supports a stance which South Africa should consider.

Against the backdrop set above, the Moon Treaty seems restrictive and somewhat a “denial of the inevitable”, while the reality is that exploitation of celestial bodies seems attainable within a reasonable time in future and it’s simply a matter of it all being economically viable (a matter of time), technology developing to required levels, spacefaring getting to affordable levels, need for natural resources getting to adequate levels to stimulate that “leap”.

The discourse for space resource extraction and utilisation as presented from the viewpoint of other similar terrestrial treaties suggests that states are to drive the conversation towards solutions and, most importantly, establish governance frameworks that are not restrictive but facilitative.

If transparency is inculcated into the process from the onset with regard to resource utilisation as is captured in Article XII of the Moon Agreement, such as openness of space facilities on the basis of reciprocity to other states and their private actors, then greater strides can be taken.

3.2 National Frameworks Relevant to Space Resource Extraction and Utilisation

3.2.1 South Africa’s National Space Legislation and Space Policy

The existing space-related governance framework in South Africa is recorded and set out in the following documents: the Non-Proliferation of Weapons of Mass Destruction Act 84 of 1993 (not relevant for this report), the Space Affairs Act 84 of 1993 and Amendment Act 1995, the Independent Communications Authority Act 13 of 2000 (not relevant for this report), South Africa’s National Space Policy, the Astronomy Geographic Advantage Act 21 of 2007 (not relevant for this report) and the South African National Space Agency Act 36 of 2008.

The Space Affairs Act was assented to on 2 July 1993 and was amended in 1995. The amendments are not relevant for the purpose of this analysis. The purpose of the Space Affairs Act is to “provide for the establishment of a Council to manage and control certain space affairs in the Republic; to determine its objects and functions; to prescribe the manner in which it is to be managed and controlled; and to provide for matters connected therewith”.[20]

[20] Government of South Africa, 1993, *Space Affairs Act of 1993*. Available at: http://www.gov.za/sites/www.gov.za/files/Act84of1993.pdf [Accessed May 22, 2017].

The Space Affairs Act concerns regulation and oversight of space-related activities and creates obligations on the state to supervise and regulate space activities, ensuring compliance with international laws. It further allows the department to establish the relevant structures (i.e. authoritative bodies) to oversee and assist with regulation of space activities and to establish regulatory frameworks (i.e. conditions for licencing) to regulate space activities.[21]

The Space Affairs Act empowers the Minister of the Department of Trade and Industry to determine a general space policy and creates the obligation of each minister, government institution or body to exercise its powers and duties in accordance with such policy. Section 4 of the Space Affairs Act establishes a South African Council for Space Affairs, and Sections 5–8 deal with the composition of Council, how and when they are to meet, and committees the Council may establish to assist with the performance of its functions, including the appointment of members, termination of membership and remuneration.[22]

Section 9 of the Space Affairs Act permits the minister to appoint a board of inquiry to adjudicate any matter or appeal in terms of the Act, whereas Section 10 empowers the minister to appoint inspectors to ensure compliance with the Space Affairs Act.[23]

Section 11 introduces the obligation of any persons involved in space activities having to obtain a licence to be issued by the Council, and the section reads as follows: "No person shall perform the following activities, except in terms of a licence issued by the Council, (subject to provisions of section 20), namely (a) any launching from the territory of the Republic; (b) any launching from the territory of another state by or on behalf of a juristic person incorporated or registered in the Republic; (c) the operation of a launch facility; (d) the participation by any juristic person incorporated or registered in the Republic, in space activities, (e) entailing obligations to the State in terms of international conventions, treaties or agreements entered into or ratified by the Government of the Republic that which may affect national interests; and (g) any other space or space-related activities prescribed by the Minister".[24]

Sections 12–16 deal with representations regarding licencing; the amendment, suspension and revocation of licencing; duties and liabilities of licensee for damages resulting from licensee's conduct in terms of domestic and international law; action of the licensee holder in case of accident, incident or potential emergency; and appeal to the minister by anyone who is aggrieved by any decision of the council or delegate. Section 17 deals with revision by court of law of decisions made by the minister and council or delegates, while Section 18 empowers the minister and governmental bodies to delegate their duties and responsibilities (Government of South Africa 1993).[25]

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[21] Government of South Africa, 1993, *Space Affairs Act of 1993*.

[22] Government of South Africa, 1993, *Space Affairs Act of 1993*.

[23] Government of South Africa, 1993, *Space Affairs Act of 1993*.

[24] Government of South Africa, 1993, *Space Affairs Act of 1993*.

[25] Government of South Africa, 1993, *Space Affairs Act of 1993*.

Section 19 imposes confidentiality obligations and prohibits on any member of committee, council, employee, inspector or anyone else related to these activities from disclosing any information to unauthorised third parties whether within South Africa or outside.

Sections 20 and 21 address limitations of liability and negate against assurances or guarantees, and Section 22 concerns regulations, including the following relevant provisions: "(a) the manner in which the functions of the Council shall be performed; (b) the procedures to be followed when applying for a licence; (c) the measures to be taken in order to **protect the national interests** of the Republic; (d) subject to the provisions of any other law, the **safety measures** and **minimum safety standards** concerning any space or space-related activity; (e) the disclosure of information in terms of section 19; (f) the conditions on which and circumstances under which inspections or investigations shall be conducted and the procedures to be followed in connection therewith; (g) the application of provisions of international conventions, treaties and agreements relating to space, entered into or ratified by the Government of the Republic; (h) the procedures to be followed in connection with an appeal to the Minister under section 16 (1), and the period within which such an appeal shall be noted; (i) the **disclosure, marketing and transfer of technologies, capacities and products** of the space industry outside the Republic; (j) the **designation, disposal of and alienation or degrading of any technological asset, capability, facility or industry deemed by the Minister as being of a strategic or indispensable nature** to the Republic; and (k) in general, any matter which shall or may be prescribed by or under this Space Affairs Act and which is aimed at achieving the objects of this Space Affairs Act".[26] To date, no regulations have been published in respect of this Act.

Section 21 establishes offences and heavy penalties for noncompliance of any obligations under the Space Affairs Act,[27] whereas Section 24 permits the minister to enter into and ratification of conventions, treaties and agreements.[28]

In comparison to the Space Affairs Act,[29] the South African National Space Agency Act[30] was assented to on 11 December 2008 but only commenced on 2 December 2010. The purpose of the SANSA Act[31] is as follows:

> *To provide for the promotion and use of space and co-operation in space-related activities, foster research in space science, advance scientific engineering through human capital, support the creation of an environment conducive to* ***industrial development in space*** *technologies within the framework of national government policy, and for that purpose to establish the South African National Space Agency; to provide for the objects and functions*

[26] Government of South Africa, 1993, *Space Affairs Act of 1993*.

[27] Government of South Africa, 1993, *Space Affairs Act of 1993*.

[28] Government of South Africa, 1993, *Space Affairs Act of 1993*.

[29] Government of South Africa, 1993, *Space Affairs Act of 1993*.

[30] Government of South Africa, 2008, *South African National Space Agency Act*. Available at: http://www.gov.za/sites/www.gov.za/files/31729_1385_0.pdf [Accessed May 22, 2017].

[31] Government of South Africa, 2008, *South African National Space Agency Act*.

of the South African National Space Agency and for the manner in which it must be managed and governed; and to provide for matters connected therewith.[32]

The SANSA Act authorises the implementation of the space policy and further establishes the Agency to implement space activities. In terms of South Africa's space policy, South Africa commits itself to utilising outer space for peaceful purposes and the benefit of all humankind and developing and maintaining a robust and appropriate set of space capabilities, service and products to support national priorities through coordination and cooperative governance.[33] South Africa also commits to being a responsible user of the space environment and will ensure that all public and private sector activities are conducted in accordance with national legislation, relevant international treaties and appropriate international best practices.[34]

Furthermore, South Africa states in the space policy that it will seek to promote research and development in space science and technology, foster development of domestic industry towards greater levels of national self-sufficiency and international competitiveness in space technology and its applications through utilising domestic commercial space capabilities and services to the maximum extent possible and cooperate with other nations in mutually beneficial and peaceful uses of outer space, with a focus on extending the benefit of space technology to the African continent through the pursuit of cooperative activities with African countries.[35]

The objectives of the National Space Policy are to (a) enhance international cooperation, (b) promote and enhance space awareness across all governmental departments and industries public and private, (c) develop adequate space capabilities, (d) develop and foster national space infrastructure, (e) strengthen the space technology base and (f) improve cooperative governance and coordination among intra-governmental and inter-agency cooperation, optimising the use of resources.[36]

As its way of promoting the domestic space industry, the space policy envisions developing an industrial framework, building capacity in domestic industry, creating supportive regulatory environment for national space activities, managing innovation and technology transfer to and from space sector and promoting competitiveness of space industry.[37]

None of the aforesaid documents specifically relate to resource extraction and utilisation, but they do promote and encourage overall development and enhancement of space and space-related activities within South Africa and internationally.

[32] Government of South Africa, 2008, *South African National Space Agency Act*.

[33] Government of South Africa, 2009, *South Africa's National Space Policy*. Available at: http://africanremotesensing.org/Resources/Documents/Nat_Space_Policy_Doc_A3_pages_final.pdf [Accessed May 22, 2017].

[34] Government of South Africa, 2009, *South Africa's National Space Policy.*

[35] Government of South Africa, 2009, *South Africa's National Space Policy.*

[36] Government of South Africa, 2009, *South Africa's National Space Policy.*

[37] Government of South Africa, 2009, *South Africa's National Space Policy.*

3.2.2 The United States Commercial Space Launch Competitiveness Act (CSLCA) of 2015

Briefly, the CSLCA is a United States (US) Government Act that updates US legislation with regard to commercial space. The Act primarily aims at engendering growth in the commercial space sector, specifically with regard to tourism and mining. With regard to this, the Act also aims to streamline the regulatory process by (for instance) curtailing Federal Aviation Authority (FAA) involvement in what is seen as an incubatory phase (or "learning period") in commercial space development.[38]

Essentially the Act looks to take US laws like the 1992 Land Remote Sensing Policy Act, the 1998 Commercial Space Act and the 2005, 2008 and 2010 National Aeronautics and Space Administration Authorization Acts. Therefore, the 2015 Act is part of a combination of codified laws and policies.[39]

Briefly, the Act discusses four main areas: encouraging private aerospace competitiveness and entrepreneurship, commercial remote sensing, the office of space commerce and space resource exploration and utilisation.[40]

While the Act mainly concentrates on tightening understanding of US space policy and making minor adjustments to the wording of other space Acts, the final (albeit brief) section concerning space mining, and the relevant rights attached to the activity, has garnered the most public attention.[41]

While the Act was bipartisan in adoption, opposition thereto from within the United States has come from a number of angles: the House Democrats, the American Association for Justice, Alliance for Justice, Center for Justice & Democracy, Consumer Watchdog, National Consumers League, Network for Environmental and Economic Responsibility of United Church of Christ, Protect All Children's Environment and Public Citizen, to name a few. Basic grievance is the act that prohibits the FAA from implementing passenger safety regulations (for at least a 10-year period). Connected to this, the Act has a potential negative impact on the rights of individuals by requiring a spaceflight liability waiver.

More politically, the Act imposes federal jurisdiction on states without any congressional hearings to examine potential unintended consequences. Another main contention is that the Act establishes controversial property rights which haven't met any review and pose a number of unresolved legal and policy issues.[42]

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[38] U.S. Congress, 2015, *H.R.2262 – U.S. Commercial Space Launch Competitiveness Act*. Available at: https://www.congress.gov/bill/114th-congress/house-bill/2262/text [Accessed May 22, 2017].

[39] Smith, M., 2015, *Space Law Activities*. Available at: http://www.spacepolicyonline.com/space-law [Accessed May 22, 2017].

[40] U.S. Congress, 2015, *H.R.2262 – U.S. Commercial Space Launch Competitiveness Act*.

[41] Foust, J., 2015, *Staking a claim to space resources*, The Space Review. Available at: http://www.thespacereview.com/article/2883/1 [Accessed May 22, 2017].

[42] Messier, D., 2015a, *House Democrats Slam SPACE Act as 'Commercial Space Industry Wish List'*, Parabolic Arc. Available at: http://www.parabolicarc.com/2015/05/21/house-democrats-slam-space-act-commercial-space-industry-list/ [Accessed May 22, 2017].

Meta-criticism for the Act is that it reads more like an industry "wish list", with little actual concern for spaceflight participants. Cited here is that major parts of the Act were largely lobbied for by the space industry seeking policy clarification and that the Act is written as a response thereto.[43]

There are numerous and varied responses to the Act by the international community (both for and against), many of which discuss the potential violations the Act poses to the United Nations Outer Space Treaty of 1967.

President Obama signed the legislation into law on 25 November 2015, which had been passed by the House of Representatives in May of that year.

3.2.3 Existing or Developing Frameworks Among Other Countries

While the United States leads the international community in its formulation and enactment of a legal framework on resource extraction and utilisation of space with its passage of the CSLCA of 2015, many countries lack such a coherent framework for regulating and managing resource extraction in space. Despite this, national frameworks do exist for regulating general space activities among most spacefaring countries, and recent initiatives by countries such as Luxembourg and the United Arab Emirates demonstrate progress for drafting space resource extraction-specific frameworks.

Therefore, this section will assess regional trends and common objectives of spacefaring countries to achieve an understanding of these countries and their potential to develop resource extraction frameworks. This section will also provide an overview of recent attempts by countries to develop national frameworks specific to regulating resource extraction in space.

Africa: For purposes of this section, the general space frameworks for Algeria, Egypt and Nigeria are considered as South Africa's space policies are analysed elsewhere in this report. Being defined according to their space capabilities (in terms of national space industries) and the history of their space launch and development programmes, Algeria, Egypt and Nigeria are considered emerging space nations.[44]

Algeria (represented by the Algerian Space Agency [ASAL]), Egypt (represented by the National Authority for Remote Sensing and Space Sciences [NARSS]) and Nigeria (represented by the National Space Research and Development Agency [NASRDA]) share similar objectives among their space programmes, namely, the use of space for achieving social and economic benefits that contribute towards national development objectives. These countries do not have space resource extraction frameworks yet developed, and their current space programmes largely feature

[43] Messier, 2015a, *House Democrats Slam SPACE Act as 'Commercial Space Industry Wish List'.*

[44] Martinez, P., 2016, *Africa in Space,* Space and Society Course, University of Cape Town.

satellite development and deployment for communications and Earth observation missions.

However, Nigeria's NASRDA does envision in its founding legislation to "develop national strategies for the exploitation of the outer space and make these part of the overall national development strategies…"[45] suggesting that any future use of space resources would again be done towards achieving development objectives.

Given the strong emphasis on the social and economic benefits of space for meeting national development objectives among these African countries, this indicates that any future development of space resource extraction frameworks would be done so with an aim towards achieving the same or similar goal.

Asia: Compared to African countries, space programmes in Asia are more advanced and expansive including those in China, India and Japan. Unlike the African countries described above, China and Japan are considered established space nations, and India is considered an intermediate space nation based on their space capabilities and space launch and development programmes.[46]

China, through its China National Space Administration (CNSA), has historically emphasised space activities for spurring technological development and utilising space applications for stimulating economic development.[47] However, China has recently pursued additional activities in space, including manned spaceflight, and is increasingly exploring the military applications of space.[48]

India, however, via its space agency the Indian Space Research Organisation (ISRO) has also traditionally engaged in space activities, especially satellite launches and operations, for the purposes of communications and Earth observation. "Since inception, the Indian space programme has been orchestrated well and had three distinct elements such as, satellites for communication and remote sensing, the space transportation system and application programmes".[49] As such, it has been oriented towards using space activities for achieving national development objectives but is now shifting focus to also include scientific and research missions as part of its space programme as seen with the launch of ASTROSAT, an astronomy research satellite.[50]

Japan also finds its space programme, largely driven through the Japan Aerospace Exploration Agency (JAXA), changing in recent years and expanding beyond space applications, including communications and Earth observation to military applications with the passage of the Basic Space Law in 2008. Although Japan similarly as

[45] Government of Nigeria, 2010, *National Space Research and Development Agency Act*, Abuja. Available at: http://lawnigeria.com/LawsoftheFederation/NATIONAL-SPACE-RESEARCH-AND-DEVELOPMENT-AGENCY-ACT-2010.html [Accessed May 22, 2017].

[46] Martinez, 2013, *Role of COPUOS in promoting sustainability of outer space activities.*

[47] Suzuki, K., 2016, *Asia in Space,* Space & Society Course, University of Cape Town.

[48] Suzuki, 2016, *Asia in Space.*

[49] Indian Space Research Organisation, 2016, *Genesis*. Available at: http://www.isro.gov.in/about-isro/genesis [Accessed May 22, 2017].

[50] Suzuki, 2016, *Asia in Space*.

China and India lacks a space resource extraction framework, its existing legislation does suggest guiding principles for future development of such a framework. These six principles are found in the Basic Space Law and include the peaceful use of space, improvement of people's lives, development of industry, prosperity of human society, promotion of international cooperation and consideration for the environment.[51]

Finally, although not as significant a space power as those above, the United Arab Emirates (UAE) as represented by the UAE Space Agency deserves mention as it has publicly declared its intention to introduce a national space law in 2016 that will govern human space exploration and commercial activities such as mining.[52] However, given its proposed objectives, including to "provide a competitive and regulatory environment that will attract the private sector and investments in the field of space",[53] the UAE may be positioning its space industry and framework, including that for space resource extraction, as a competitor to others and therefore may contain industry-friendly regulations for attracting investment.

Given the above on Asian space practices, the changing nature of Asian space programmes does not present clear indications on how space resource extraction frameworks could be developed among these countries with an adoption of common approaches. The national development and political interests of each country vary, and as such may result in varied approaches towards such frameworks.

Europe: Europe includes some of the world's leading space powers, including the European Space Agency (ESA) as the intergovernmental space organisation linked to the European Union and the Russian space agency Roscosmos. Given the European principles towards developing a common approach to space,[54] ESA and Roscosmos will be analysed primarily alongside Luxembourg, which itself has recently made attempts to distinguish itself for space mining activities. Western Europe, as represented by ESA, is considered an established space nation alongside Russia based on their space capabilities and space launch and development histories.[55]

ESA represents an advanced space agency that conducts activities across various areas, including Earth observation and remote sensing, communications, scientific and research expeditions and manned space flight. As ESA reports itself, "its Member States agreed to provide for and to promote, for exclusively peaceful purposes, cooperation among them in space research and technology and their space applications, with a view to their being used for scientific purposes and for

[51] Suzuki, 2016, *Asia in Space.*

[52] Barnard, L., 2016, *UAE to finalise space laws soon*, The National. Available at: http://www.thenational.ae/business/aviation/uae-to-finalise-space-laws-soon [Accessed May 22, 2017].

[53] Messier, D., 2015b, *UAE Space Agency to Unveil Strategy, Operational Plan on Monday*, Parabolic Arc. Available at: http://www.parabolicarc.com/2015/05/24/uae-space-agency-unveil-strategy-operational-plan-monday/ [Accessed May 22, 2017].

[54] European Space Agency, 2016, *Law at ESA*. Available at: http://www.esa.int/About_Us/Law_at_ESA/Law_at_ESA [Accessed May 22, 2017].

[55] Martinez, 2013, *Role of COPUOS in promoting sustainability of outer space activities.*

operational space applications systems".[56] These goals do not include commercial, including space mining, activities; however, ESA's industrial policy rules and regulations, although largely focusing on return on investments for ESA member states, do suggest that ESA is interested in ensuring European companies remain competitive for space activities, likely to include space mining, and thus may lend itself towards formulating in the future a space resource extraction framework that seeks a similar objective to "improve the world-wide competitiveness of European industry",[57] and therefore characterise itself as industry-friendly.

Similarly, Russia's Roscosmos is a leading international space stakeholder and conducts space activities across many areas, including Earth observation for environmental and disaster management, navigation systems, communications, manned spaceflight and space scientific research.[58] Although neither space resource extraction activities have taken place nor have frameworks developed in Russia for regulating these kinds of activities, there have been reports of Russian research institutes and Roscosmos collaborating on projects to settle the moon for mining of resources.[59] Although the actual extraction of resources under the Luna-25 mission would likely not take place for more than a decade, this proposed Roscosmos space activity does suggest Russia's seriousness in accessing the rare Earth mineral market through space mining.[60]

Finally, Luxembourg, although not nearly the size of ESA or Roscosmos in its breadth of space activities, is seeking to develop a niche market for the space resource extraction industry by developing a national framework, named spaceresources.lu, for regulating space mining. Luxembourg currently serves as the headquarters of the largest satellite telecommunications company, SES, and seeks to attract industry in the space mining sector by supporting research and development for space mining technologies that these companies could later deploy and by directly investing in companies. However, media reports do suggest that Luxembourg will be developing industry-friendly policies that prove similar to the US CSLCA of 2015 in terms of their interpretation of international space law. As Luxembourg's economic minister stated, "These rules prohibit the appropriation of space and celestial bodies but they do not exclude the appropriation of materials which can be found there".[61]

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56 European Space Agency, 2015, *Regulations of the European Space Agency: Industrial Policy Rules and Regulations*. Available at: http://esamultimedia.esa.int/docs/LEX-L/Contracts/ESA_REG_009_Geo_return_coeff_(extranet).pdf [Accessed May 22, 2017].

57 European Space Agency, 2015, *Regulations of the European Space Agency: Industrial Policy Rules and Regulations.*

58 Roscosmos, 2016, *Activities*. Available at: http://en.federalspace.ru/20269/ [Accessed May 22, 2017].

59 Jamasmie, C., 2014, *Russia pushes forward plans to mine the moon*. Available at: http://www.mining.com/russia-pushes-forward-plans-to-mine-the-moon-13769/ [Accessed May 22, 2017].

60 Rosenfeld, E., 2015, *Russian firm proposes $9.4B moon base for mining*, CNBC. Available at: http://www.cnbc.com/2015/01/02/russian-firm-proposes-94b-moon-base-for-mining.html [Accessed May 22, 2017].

61 Amos, J., 2016a, *Luxembourg to support space mining*, BBC. Available at: http://www.bbc.com/news/science-environment-35482427 [Accessed May 22, 2017].

Americas: As the United States and its CSLCA of 2015 are assessed elsewhere in this report, the purpose of this section is to summarise the space programmes of other countries in the Americas. Similar to some in Africa and Asia, the space programmes of the Americas are more limited in scope as compared to their European counterparts, as they primarily emphasise satellite communications and Earth observation missions. Only Brazil is considered an intermediate space nation making the step from emerging to established space nation, while all other South American countries are considered as emerging based upon their existing space capabilities and space launch and development programme histories.[62]

As such, CONAE (representing Argentina), AEB (representing Brazil), CCDE (representing Colombia), AE (representing Mexico), CONIDA (representing Peru) and ABAE (representing Venezuela) have been primarily oriented towards using space for achieving national development objectives, despite some of their former military beginnings.[63] In some countries, such as Colombia for example, many space activities are driven outside of formal space agencies, including at universities.

Although no space resource extraction frameworks exist formally among these programmes in the Americas, there are common themes around the use of space for meeting development goals and ensuring space sustainability for continued use. Given this, these potential principles may lend themselves towards orienting and informing future frameworks for resource extraction and use in space and characterise themselves differently than other existing or developing frameworks as seen in the United States, the UAE or Luxembourg.

[62] Martinez, 2013, *Role of COPUOS in promoting sustainability of outer space activities.*

[63] Lopez, L.D., 2016, *Regional Space Cooperation: Spotlight on Latin America,* Space & Society Course, University of Cape Town.

Chapter 4
Analysis of Views of Established and Emerging Space Nations with Regard to Space Mining and US CSLCA of 2015

Space exploration has to date been undertaken by emerging, intermediate, and established economies. The grouping of countries into emerging, intermediate, and established categories in relation to space activities is not a straightforward process. However, countries may be grouped into emerging, intermediate, and established on the basis of world government expenditures for civil space programs.[1] This section will follow the same principle.

Emerging countries in space exploration are those countries that are relatively new to outer space research projects and to the launching of satellites into space and application of the same for their economic growth. There are a number of countries falling into this category: South Africa, Nigeria, Egypt, Algeria, Ghana, Kenya, Angola, Morocco, Saudi Arabia, Turkey, Kuwait, Indonesia, Chile, Malaysia, Argentina, Pakistan, and South Korea, just to mention a few.

On the other hand, established and intermediate economies (or space powers) are those with more advanced capabilities to design and develop autonomous space systems as well as launch and operate autonomous space systems. The countries falling into this category include the USA, Western Europe, Russia, China, India, Canada, Israel, South Korea, Japan, and Brazil.

The US CSLCA, which was passed by the US senate in November 2015, could arguably generate debates and strong reactions among emerging, intermediate, and established space nations. Such debates could potentially occur since US CSLCA entitles American companies to extract, possess, transport, use, and sell natural resources extracted from celestial bodies. If this venture is successful, not only would it potentially violate various international treaties but could also give the USA more economic and political power over the other nations.

It is claimed that about 1500 asteroids are within easy reach from Earth and about 10% of them have valuable resources. Space resource mining on asteroids is not only for minerals but also for the trapped water in these asteroids. The water could be used

[1] Martinez, 2016, *Africa in Space*.

A. Froehlich (ed.), *Space Resource Utilization: A View from an Emerging Space Faring Nation*, Studies in Space Policy 12,
https://doi.org/10.1007/978-3-319-66969-4_4

to provide hydrogen fuel for space vehicles, thereby acting like refueling stations for rockets and satellites in orbit. Access to such resources could give the USA a cutting edge over other established, intermediate, and emerging economies, and it is therefore useful to understand these other countries' views on the matter.

This section will therefore examine the position of various space nations on asteroid mining from three perspectives, namely, (1) technology readiness level, (2) perspectives of intermediate and established economies, and (3) perspectives of emerging economies.

4.1 The Technological Readiness Level of Established, Intermediate, and Emerging Economies for Space Resource Mining

Prior to understanding the views of other space nations on the US CSLCA of 2015, it is important to understand these countries' technology readiness level in relation to space resource mining. Their respective technology readiness level might determine whether or not other space nations would be able to also embark on space resource mining in the near future. Their technology readiness level could further determine whether they would support the US CSLCA or refute it.

4.1.1 The Influence of the Private Sector on Space Nations' Technological Readiness Level

There are currently two main asteroid mining companies, Deep Space Industries (DSI) and Planetary Resources, which have the same basic goal (i.e., asteroid resource mining) but with somewhat different intended mining methods being employed. DSI has offices in the USA, Luxembourg, and the European Union and defines itself as an international mining company.[2] Planetary Resources is a US company which was initially formed in 2010 and later reorganized and renamed in 2012. As can be seen, both companies are mostly based in established economies.

Planetary Resources, together with the Keck Institute for Space Studies (KISS),[3] has independently conducted feasibility studies for asteroid mining and retrieval in 2012, namely, "Asteroid Mining Venture" and "Is Asteroid Mining Possible?." Planetary Resources is currently developing small, low-cost low Earth orbit (LEO) telescopes to survey asteroids on demand, from Earth orbit. They later plan to

[2] Deep Space Industries, 2017, *Who We Are*. Available at: https://deepspaceindustries.com/business/ [Accessed May 23, 2017].

[3] Keck Institute for Space Studies, 2016, *Asteroid Retrieval Feasibility Study*. Available at: http://www.kiss.caltech.edu/study/asteroid/asteroid_final_report.pdf [Accessed May 22, 2017].

Table 4.1 Timetable depicting possibility of asteroid mining

	2015	2025	2035	2045	2055	2065	2075	2085
Robotics		High-resolution mechanical replication						
				Autonomous integrated circuit replication				
					Self-replicating space factories			
Resources	Asteroid resource surveys							
			Autonomous refining					

develop two larger types of prospecting craft. The "interceptor" will act as a longer-range prospector, being able to intercept any asteroids that come within 10–30 times the Earth-moon orbit (something which occurs quite frequently). Finally, the "rendezvous prospector" would be able to travel halfway across the inner solar system to gather detailed information about asteroids—including size, shape, rotation, and density. While it is clear that they plan to develop craft to return samples and eventually return whole asteroids, they have not yet made any further details publicly.[4]

DSI, on the other hand, is taking a more aggressive approach. They currently have two planned spacecraft. The "Firefly," constructed from low-cost materials, will prospect for suitable asteroids to mine. The larger "Dragonfly" craft will then go and start collecting asteroid material. They appear to have numerous more ambitious concept sketches for future craft, but again they haven't released many details yet.[5]

The two major conclusions from the KISS study are (1) that it appears feasible to identify, capture, and return an entire ~7-m diameter, ~500,000-kg near-Earth asteroid to a high lunar orbit using technology that is or could be available in this decade and (2) that such an endeavor may be essential technically and programmatically for the success of both near-term and long-term human exploration beyond low Earth orbit.[6]

Adam J. Crowl on an article for ICARUS has plotted the following development timetable over the next century based on the paper by Gerald D. Nordley and Adam J. Crowl, as follows (Table 4.1).

Through these private companies, the countries in which they operate therefore have a high technological readiness level in relation to space resource mining. In addition to the USA, European countries and Luxembourg would therefore be potential candidates for space resource mining ventures. This would of course depend on the level of infrastructure in place in these countries, the costs to be incurred, as well as the countries' financial capabilities. For example, according to the KISS study, the cost for a future mission to identify and return a 500-ton asteroid to low Earth orbit is ~$2.6 billion USD, ignoring the costs to develop the infrastruc-

[4] O'Neill, I., 2017, *Asteroid Mining: Booming twenty-first Century Gold Rush?*, Discovery News. Available at: http://news.discovery.com/space/asteroids-meteors-meteorites/could-asteroid-mining-drive-21st-century-space-industry-130204.htm [Accessed May 22, 2017].

[5] O'Neill, 2017, *Asteroid Mining: Booming 21st Century Gold Rush?*

[6] Keck Institute for Space Studies, 2016, *Asteroid Retrieval Feasibility Study.*

ture necessary to process the materials in the asteroid.[7] However, the return on investment could be appealing. Planetary Resources estimates that a 30-meter-long platinum-rich asteroid could contain $25–$50 billion USD worth of platinum at today's prices.[8] Clearly, once the proper infrastructure is in place, there is potential for significant profit.

4.1.2 GDP Expenditure of Emerging, Intermediate, and Established Economies on Space Projects

Technological readiness could also be dependent on space nations' GDP expenditure on space projects. The following tabulates the comparison between states on budget for each country's space program. Table 2.1 is sorted from the highest percentage spend according to national GDP (see Appendix C).

Some of the emerging countries have also played their part by allocating their national expenditure on space projects; for South Africa (SA), budgets on space development allocated by its Department of Science and Technology (DST) were $44 M between 2009 and 2010, $47 M between 2010 and 2011, and $50.8 M between 2011 and 2012.[9] So far SA is the only African country with specific space legislation and a dedicated regulatory body. Nigerian space agency known as NASRDA spends $13 million on its first satellite, Nigeria Sat-1, and launched from a spaceport in Russia on 13 May 2007.[10] On the other hand, Ghana was admitted to the UN COPUOS in 2013, and oil-rich country Angola has recently purchased a $300-M telecommunication satellite from Russia. The first satellite for Angola known as AngoSat 1 will be launched in the third quarter of 2017.[11] Kenya has also shown interest by joining the African Resource Management Constellation (ARM-C) project though it is still developing its own space agency.[12]

However, in spite of some of their GDP expenditure being dedicated to space exploration-related projects, not all emerging, intermediate, and emerging space nations view space resource mining as a priority. The following subsections will

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[7] Planetary Resources, n.d., *Asteroid Composition*. Available at: http://www.planetaryresources.com/asteroids/#asteroids-types-of-asteroids [Accessed May 23, 2017].

[8] Kumar, K., 2012, *Sorry, But This Plan To Mine Asteroids Is A Big Load Of Junk*, Business Insider. Available at: http://www.businessinsider.com/planetary-resources-seeks-to-mine-asteroids-but-skeptics-say-plan-amounts-to-hot-air-2012-5 [Accessed May 22, 2017].

[9] The Tauri Group, 2011, *The South African Space industry*. Available at: http://www.spacesa.org/resources/South_Africa_Space_Industry2011.pdf [Accessed May 29, 2017].

[10] IBT times, 2013, *Nigeria's Space Program: A Rare Glimpse Inside The West African Nation's Satellite Operation*. Available at: http://www.ibtimes.com/nigerias-space-program-rare-glimpse-inside-west-african-nations-satellite-operation-1411236 [Accessed May 29, 2017].

[11] telecompaper, 2017, *Angosat 1 satellite to launch in Q3*. Available at: https://www.telecompaper.com/news/angosat-1-satellite-to-launch-in-q3--1182558 [Accessed May 29, 2017].

[12] EEpublishers, 2010, *Space and Beyond*. Available at: http://www.ee.co.za/article/space-and-beyond-7.html [Accessed 29 May 29, 2017].

examine space nations' views on space resource mining while drawing upon information from their space legislations and the UN treaties which they ratified.

4.2 Intermediate and Established Economies' Perspectives on Space Projects, Asteroid Mining, and the US CSLCA of 2015

In order to understand the perspectives of intermediate and established economies on space resource mining, an overview of the various UN space treaties ratified and signed by these countries will first be provided. A discussion is then proposed around intermediate and established economies' perspectives on space projects as well as resource extraction and utilization, based on their current legislations. Lastly, the countries' views on the US CSLCA of 2015 are then discussed.

4.2.1 UN Space Treaties Ratified and Signed by Intermediate and Established Economies

Intermediate and established economies have been investigating the possibilities of space exploration since the early 1900s. For example, an influential paper[13] was published in the USA on a method to reach extreme altitudes using solid- and liquid-fueled rocketry as early as in 1919. The first satellite, Sputnik, was launched on 4 October 1957 by Russia.[14] Ever since, established economies (and more recently intermediate economies) have been using space exploration for a wide range of activities and for diverse purposes: political, socioeconomic, scientific, military, etc. Moreover, their current views on and vision for space exploration are often reflected in the UN space treaties which they have signed or have not signed.

To date, the intermediate and established economies investigated in this section have ratified and signed a number of UN treaties. For example, the Outer Space Treaty (1966), Rescue Agreement (1972), Liability Convention (1972), and Registration Convention (1976) were ratified by the USA, Russia, India, Republic of Korea, Israel, and Japan.[15]

All Western European countries signed and ratified the Outer Space Treaty (1966), but only 2 (Austria and Netherland) of the 18 countries signed and ratified the Moon Agreement (1979), while Belgium was by accession. France signed but

[13] Goddard, R.H., 1919, *A method of reaching extreme altitudes*, The Smithsonian Institution, Washington, DC.

[14] National Archives, n.d., *Space Exploration*. Available at: http://www.archives.gov/research/alic/reference/space-timeline.html [Accessed May 22, 2017].

[15] United Nations Committee on the Peaceful Uses of Outer Space, 2017, *Status of International Agreements relating to activities in outer space as at 1 January 2017*, United Nations, Vienna.

did not ratify the Moon Agreement (1979). More details about the ratification status of other established countries for the UN treaties can be found in Appendix A.

Article II of the Moon Agreement (1979) asserts that *the moon and its natural resources are the common heritage of mankind…* and goes on to oblige state parties to *establish an international regime, including appropriate procedures, to govern the exploitation of the natural resources of the Moon as such exploitation is about to become feasible*. It is interesting to note that most of the intermediate and established space nations have not ratified the Moon Agreement to date. Consequently, even though these nations (with the exception of the USA) currently do not have any legislations pertaining to space resource mining (see following sections), they definitely have room to maneuver and make strategic decisions in that regard in the future.

4.2.2 Intermediate and Established Economies' Perspectives on Space Projects and Asteroid Mining

The USA is the only country, to date, that has implemented a legislation which supports and promotes the commercial exploitation of space resources by US citizens and private companies.[16] Others have yet to state their position on the matter, let alone update their legislations.

According to their current legislation, established economies (with the exception of the USA) focus on scientific, socioeconomic, as well as military issues in relation to their space activities. For example, Russia's legislation promotes the application of space science, technology, and industry for scientific, technical, socioeconomic, and defense tasks of the Russian Federation.[17] No explicit mention of asteroid mining has been made to date.

India is the only established space nation which has not yet drafted a specific space law. The Indian space program is currently guided by the *Allocation of Business Rules for the Department of Space* as well as by related legislations and regulations of the Government of India.[18] However, in a recent Round Table Conference on "Commercialization and Privatization of Outer Space: Issues for National Space Legislation," key local players ascertained the need to draft an Indian space law.[19] India's current vision is to encourage participation from private

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[16] U.S. Congress, 2015, *H.R.2262 – U.S. Commercial Space Launch Competitiveness Act*.

[17] Government of the Russian Federation, n.d., *LAW of the RUSSIAN FEDERATION "ABOUT SPACE ACTIVITY"*. Available from http://www.unoosa.org/oosa/en/ourwork/spacelaw/nationalspacelaw/russian_federation/decree_5663-1_E.html [Accessed May 22, 2017].

[18] Government of India, 2015, *The Government of India (Allocation of Business) Rules*. Available at: http://cabsec.nic.in/files/allocation/abr_rules_archive_299.pdf [Accessed May 22, 2017].

[19] New Space India, n.d., *Excepts of the 'Round Table Conference on Issues for National Space Legislation'*. Available at: http://www.newspaceindia.com/excerpts-of-round-table-conference-on-issues-for-national-space-legislation/ [Accessed May 22, 2017].

companies in order to promote competitiveness in its space sector and acquire more competence.[20] Their aim is to benefit all local industry sectors, and asteroid mining is not a main concern or aim to date.

The Republic of Korea has also adopted policies to promote private space development activities and investment in research and development but has not to date adopted any legislations regarding asteroid mining.[21] For that purpose, their legislation allows for the provision of man power for space development, tax benefits, and financial support among others. Their interest in promoting private space development activities might lead to some opportunities or interest in space resource mining and commercialization.[22]

According to the *law concerning the National Space Development Agency of Japan,* the country's scope of space-related business, as defined in their legal document, only relates to the development, launching, and tracking of artificial satellites and rockets in an integrated, systematic, and effective manner. The legislation also caters for the development of means, facilities, and equipment necessary for the above.[23] Again, asteroid mining has not yet been considered.

So far among the Western European countries, only Luxembourg has publicly shown interest in space mining and exploration. They intend to set out a formal legal framework that promotes the involvement of private organizations to extract resources (e.g., rare minerals from asteroids).[24] Other countries from Western Europe are mostly focusing on economical, security, educational, and administrative functions in the sector of outer space activities.

Canada's main focus is for peaceful promotion and the development of space, for science and technology, and for social and economic benefits for Canadians.[25] Similarly, the major focus of China which is one of the world's frontiers in space activities is to develop its economy and continuously pushing forward its modernization drive.[26] Israel's major goals include advancing infrastructural research at academic and research institution and supporting the development of innovative and unique space technologies.[27]

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[20] Government of India, 2015, *The Government of India (Allocation of Business) Rules*.

[21] Kim, D.H., 2010, *Space Law and Policy in the Republic of Korea*. Available at: http://www.unoosa.org/pdf/pres/2010/SLW2010/02-09.pdf [Accessed May 22, 2017].

[22] Government of the Republic of Korea, 2005, *Space Development Promotion Act*. Available at: http://www.unoosa.org/oosa/en/ourwork/spacelaw/nationalspacelaw/republic_of_korea/space_development_promotions_actE.html [Accessed May 22, 2017].

[23] Government of Japan, 1969, *Law Concerning The National Space Development Agency of Japan*. Available at: http://www.unoosa.org/oosa/en/ourwork/spacelaw/nationalspacelaw/japan/nasda_1969E.html [Accessed May 22, 2017].

[24] Government of Luxembourg, 2016, *Luxembourg to launch framework to support the future use of space resources*. Available at: http://www.gouvernement.lu/5653386 [Accessed May 22, 2017].

[25] Government of Canada, n.d., *Canadian Space Agency Act*. Available at: http://laws.justice.gc.ca/eng/acts/C-23.2/page-1.html#h-4 [Accessed May 22, 2017].

[26] Government of China, 2016, *China's Space Activities in 2016*. Available at: http://www.scio.gov.cn/zxbd/wz/Document/1537091/1537091.htm [Accessed May 22, 2017].

[27] Government of Israel, 2002, *The Israel Space Agency*. Available at: http://most.gov.il/english/space/isa/Pages/default.aspx [Accessed May 22, 2017].

4.2.3 *Intermediate and Established Economies' Perspectives on the US CSLCA of 2015*

The US CSLCA was made public in November 2015, and to date, with the exception of unofficial newspaper articles, there have not been any official declarations from intermediate and established economies on the matter. Even the European Union, where DSI currently has one of its offices, has not made any official statement on the matter.

It would have been interesting to ascertain these countries' perspectives on the US CSLCA, given the controversial nature of the Act and its borderline violation of international treaties, as well as economic and political implications (among others) on the international landscape. It is possible that these countries will officially put forward their views or concerns after the UN has made an official declaration on the matter.

In contrast, the space mining private sector has been quick to officially voice their full support for the US CSLCA. For example, DSI issued a press release entitled as "U.S. Makes Space History" in which it congratulates the White House and the U.S Congress *on the passage and signing of this historic legislation*. They also clearly stipulated that the act would bring more clarity and certainty for their current and future investors.[28]

The cofounder and cochairman of Planetary Resources also officially expressed his strong enthusiasm about the act further stated that *the "limitless resources" from space will help drive the world's economy and prosperity in the future*.[29] In an official press release, Planetary Resources *applauds President Obama who signed the US Commercial Space Launch Competitiveness Act*.[30]

These strong and enthusiastic statements contrast with the "silence" of intermediate and emerging economies to date, and also show the extent to which the private sector will benefit from this act.

[28] Deep Space Industries, 2015, *U.S. Makes Space History: President Obama Signs Law Enabling Commercial Exploration and Use of Space Resources*. Available at: https://deepspaceindustries.com/u-s-makes-space-history/ [Accessed May 23, 2017].

[29] Planetary Resources, 2015, *President Obama Signs Bill Recognizing Asteroid Resource Property Rights Into Law*. Available at: http://www.planetaryresources.com/2015/11/president-obama-signs-bill-recognizing-asteroid-resource-property-rights-into-law/ [Accessed March 2016].

[30] Planetary Resources, 2015, *President Obama Signs Bill Recognizing Asteroid Resource Property Rights Into Law*.

4.3 Emerging Economies' Perspectives on Space Projects and Asteroid Mining

According to the United Nations,[31] the emerging nations mostly from the developing countries, like South Africa, Algeria, Kenya, Argentina, Egypt, etc., look at space activities from development perspectives. They are able to invest in space applications to mitigate challenges relevant to their context like poverty; illiteracy; malnutrition; poor water supply; sanitation; health and disease (especially malaria); food, human, and water security; and natural disaster affecting millions of lives. This explains their meager expenditures to real space programs and their nonaggression in competing with those established countries. This however is the compelling reason why they are not dominant in the international arena as we examine their political involvement in the US CSLCA of 2015 in the resource extraction of the outer space treaty. But for the purpose of this paper, it is indispensable to do an analysis of their national laws, agenda, and future perspectives in space affairs as per resource extraction which would now be compared whether such agree with US CSLCA of 2016 in resource extraction.

Similarly to established countries in space exploration, emerging economies have also ratifications and signature to a number of treaties. For example, Pakistan, Romania, Turkey, Kuwait, and Saudi Arabia have ratifications for OST, ARRA, LIAB, REG, and the Moon Treaty, while the Republic of Korea has ratification on all the treaties but the moon.

The status quo of emerging countries as to asteroid mining and other outer space exploration remain as they were except a bold announcement by the government of Luxembourg on February 2016 declaring its intention to invest in space-based asteroid mining.[32] The statement however may mark a new era for support for asteroid mining in alliance with the USA by Luxembourg government since the report suggested that advisory board members in this mission included diplomats from Europe, America, and China. This means although there is a specific national space interest in the emerging space countries, the prospect of "gold rush" for space resource extraction is a possibility, invariably meaning there would be adoption of US CSLCA and ratification in actual sense.[33] Let us watch and see! Other countries to watch in African domain include South Africa, Nigeria, and Algeria in collaboration with the more established countries but only when space resource extraction would drive economic growth in the positive direction.[34]

[31] United Nations Office for Outer Space Affairs, 2008, *United Nations Treaties and Principles on Outer Space and related General Assembly resolutions*.

[32] De Selding, P.B., 2016, *Luxemburg to invest in space-based asteroid mining*, Space News. Available at: http://spacenews.com/luxembourg-to-invest-in-space-based-asteroid-mining/ [Accessed May 22, 2017].

[33] De Selding, 2016, *Luxemburg to invest in space-based asteroid mining*.

[34] Amos, J., 2016b, *Mars TGO probe despatched on methane investigation*, BBC. Available at: http://www.bbc.com/news/science-environment-35799792 [Accessed May 22, 2017].

It was not yet established whether it is economically feasible to get space resources to Earth, and this fact has strong implications for emerging economies. But there is agreed legal status of space resources use and governance though it is ambiguous with respect to the use of space resources, in such a way that several interpretations exist that are not internationally agreed. At the moment, actions are still going on with the UN COPUOS to issue a declaration clarifying issues related to the use of space resources. There is a need to have an international agreement on governance of space resources' use to foster investments of private industry and open new markets while preventing uncoordinated rush to space resources that can cause conflicts, as there are already more different space actors bringing competition about orbits, frequencies, and resources, with different distributive models of governance—hence the coming in of Space Traffic Management (STM). So far no official reactions were found coming from the emerging countries, against or in support of the US CSLCA. This could be the result of the time span as the act has just been passed last December.

4.4 Conclusion

With the unclear definition of appropriation and use of the space resources, the US CSLCA is not violating any legal structures. However, for the sake of conflicts that may rise due to the rush for space mining from other players of the space, Luxembourg wants to do the same by coming up with its own similar legislation by the end of the year. Some clear international regulations should be put in place. Regulations that will be guarding things like the time frame when one state or commercial company can mine one asteroid, how many can one possess at a time, and how they are going to police that as the business will be taking place in space.

Chapter 5
Analysis of the Views of Both Established and Emerging Space Nations Regarding the Topic and Also Regarding the New US CSLCA of 2015

5.1 The Social, Safety and Environmental Effects and Outcomes of Resource Extraction and Utilization

5.1.1 Social Impact of Asteroid Mining

As an alternative to terrestrial mining, asteroid mining could entail a change in the quality of life on Earth. In this point, it has been assumed that mining outer space would lead to a reduction of terrestrial mining of some rare-Earth materials such as platinum. First of all, the most noticeable primary effects, caused to miners' occupational health and safety on Earth, are the severe respiratory dysfunction caused by the inhalation of platinum salts,[1] the risk of respiratory and kidney cancer for the mining of nickel, and cardiovascular disease associated with the use of mercury for processing metals during the mining.[2] On the other side, asteroid miners would be exposed to unknown chemical mixtures, possible microbiological organisms, and a harmful dose of radiation. In addition, contamination of space objects or samples obtained in space could potentially lead to the spread of unknown diseases on Earth to which humans lack immunity to, as previously witnessed during historic land exploration. Thus, the human factor must be taken into account in the legislation for asteroid mining.[3]

Mining also has secondary effects, caused to the community not directly involved in the industry. It causes water, soil and air degradation, as China has experienced during its rapid growth due to the fossil fuel use from coal and extensive mining,

[1] Pepys, M.B., 1972, *Role of Complement in Induction of the Allergic Response,* Nature New Biology, 237(74), 157–59.

[2] Boffetta, P., et al., 2001, *Mortality from cardiovascular diseases and exposure to inorganic mercury*, Occupational & Environment Medicine, 58(7), 461–6.

[3] International Space University Space Studies Program, 2010, *ASTRA: ASteroid mining, Technologies Roadmap and Applications, Final Report*, International Space University, Strasbourg.

A. Froehlich (ed.), *Space Resource Utilization: A View from an Emerging Space Faring Nation*, Studies in Space Policy 12,
https://doi.org/10.1007/978-3-319-66969-4_5

which harms all humankind. An example of this is the degradation experienced in the Chinese environment during the country's growth, motivated by fossil fuel use from coal and extensive mining.[4]

Some communities in South Africa have also seen their lives damaged by the nationally strong mining industry. This is the case of the settlement Tudor Shaft, installed on top of mine sailings and surrounded by land contaminated by mining activities and radioactive dumps, which exposes its inhabitant to harmful radiation and dust inhalation. The suburb of Diamanthoogte, in the outskirts of the mining town Koffiefontein, also suffers the consequences of mining: Its water is supplied through a canal that comes from the mine dam.[5]

Objects falling to Earth not only impact the environment and economy; society may also be affected. A meteor explosion over Chelyabinsk, Russia, in February 2013 resulted in over 1000 reported injuries.[6] Transportation of asteroids selected for mining purposes could result in accidents and subsequent entry into the Earth's atmosphere. There is also waste disposal to consider. Whilst precious metals may be an end goal of asteroid mining, huge amounts of waste or tailings also result and need to be carefully considered. Waste cannot be merely resent into the Earth's atmosphere without considering the impact. Also, if tailings were to accidentally wind up in the Earth orbit, the result could lead to a chain reaction of collisions commonly known as the Kessler Syndrome. This would have a negative effect on the existing issue of space debris.

The fast world population growth (there are 8.5 billion people expected to live on Earth in 2025), added to the developing industrialization, is leading to an increasing consumption of natural resources. Indeed, there are prospects that the world of tomorrow is going to be characterized for conflicts for resources and, more precisely, that the next war in the Middle East is going to be triggered by the competition for water resources.[7]

Obtaining those resources from asteroids could reduce the necessity of mining on Earth. Thus, NEA mining could enable to preserve the Earth's environment and replenish contaminated water.

Society could also benefit from scientific advances in medicine and pharmacology, as the vacuum and the zero gravity of space provide an ideal scenario for material processing and the production of high-value and material purity goods, such as pharmaceuticals.[8]

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[4] Hlimi, 2015, *The Next Frontier: An Overview of the Legal and Environmental Implications of Near-Earth Asteroid Mining.*

[5] Teicher, J. G., 2014, *The Human Cost of South Africa's Mining Industry*. Available at: http://www.slate.com/blogs/behold/2014/09/09/ilan_godfrey_documents_the_impact_of_south_africa_s_mining_industry_in_his.html [Accessed May 23, 2017].

[6] Popova, O.P., et al., 2013, *Chelyabinsk Airburst, Damage Assessment, Meteorite Recovery, and Characterization*, Science, 342(6162), 1069–1073.

[7] Diekmann, A., & Richarz, H.P., 1999, *Future role and significance of space activities in reflection of global social, technological and economic trends*, Acta Astronautica, 45(11), 697–703.

[8] Meyer, Z., 2010, *Private Commercialization of Space in an International Regime: A Proposal for a Space District*, Northern Journal of International Law and Business, 30(1), 241–261.

Whilst miners have historically belonged to the working class, spaceflight has been reserved only to highly educated astronauts and, with the development of space tourism, to the highest economic class. Outer space mining can then have the power of changing the current social classes, through taking miners into space.[9]

Global awareness has drastically increased due to media broadcasts and podcasts. We can stream live video footage from the International Space Station and interact with astronauts via their respective social media accounts. The official NASA Twitter account, @NASA, recently invited local social media users to apply for the chance to attend a 1-day event on April 29, 2016, to learn about the first-ever NASA mission to travel to an asteroid and to retrieve and return samples to Earth. Participants will be able to view the completed OSIRIS-REx spacecraft and learn about several engineering challenges. This illustrates the increasing transparency and social awareness of space exploration and career opportunities within space-related activities. Disadvantages arise in access to the Internet in developing countries and the authority to participate in programmes due to citizenship, which may lead to independent programmes being conducted and an interstate competitiveness.

This illustrates that whilst career opportunities continue to grow, the audience targeted are within a certain demographic which may lead to a decline in job opportunities for other demographics. This is the case of South Africa, the largest platinum producer in the world, having over 80% of the world platinum group metals reserve. Together with Russia, the Republic holds over 90% of the world's platinum production (Africa Mining n.d.). Thus, it is probable that a lot of jobs in the mining industry will be lost and the country will lose part of its economic basis.[9] Similarly, whilst the US and Russian missions to Mars were manned, China is set for their sample return mission in 2017 using simply a space probe, eliminating the need for manned spacecrafts and labour.[10] This shows an increase in job opportunities within the Science and Technology sector however a potential decline in other sectors.

If we look back historically at incentives for land exploration on Earth, resources were the key ingredient such as pursued eastern spices by western states. Some of the benefits to the pursued state were improved infrastructure, transport and increased job opportunities; however, this also resulted in slavery and usurped territories. During the development of the asteroid mining industry, some developing countries may be left behind whilst empowering only those countries enough rich and technologically prepared to participate.[9] Ismail Serageldin defined "scientific apartheid" as:

There is a real danger that the benefits of proprietary science would serve to bring more and more to the privileged rather than serve the needs of the billions of the marginalized poor and their children. Developing countries will not be able to

[9] International Space University Space Studies Program, 2010, *ASTRA: ASteroid mining, Technologies Roadmap and Applications, Final Report*.

[10] Avins, J., 2016, *China's "Jade Rabbit" rover found a new kind of moon rock*, QUARTZ. Available at: http://qz.com/581824/chinas-jade-rabbit-rover-found-a-new-kind-of-moon-rock/ [Accessed May 23, 2017].

adjust fast enough to the needs of the competitive global economy of science-based production and knowledge-based income.[11]

5.1.2 Safety Impact of Asteroid Mining

5.1.2.1 Background on Space Safety

More than 50 years of spaceflight has shown that the issue of safety is paramount at various stages of planning for any mission. There is little margin for error as this could be catastrophic not only for the crew but at times the populace who happen to be in the line of flight. About 222 known fatalities have occurred in space-related activity – covering astronauts/cosmonauts and rocket explosions during processing, testing, launch preparations and launch.[12] Experience from accidents from the Apollo 1 fire on 27 January 1967 to Columbia involved the loss of human lives and was highly publicized; on the Russian side, it was revealed that several fatal mishaps also occurred, from the death of Dobrovolski, Patsayev, and Volkov whilst returning from the Salyut 1 space station in 1971 to the explosion of Vostok-2M launch vehicle during fuelling on 18 March 1980, among others.

5.1.2.2 Space Safety

Roland and Moriarty[13] defined safety in a system as a quality of system that allows it to function under predetermined conditions with acceptable minimum risk of accidental loss. Sgobba[14] noted that "space safety" includes the protection of human life during *all* phases of a space mission (manned or unmanned) from launch to re-entry and the protection of ground and flight high-value systems. Thus, safety generally denotes protection from harm; this might apply to humans, equipment and communication. Also outlined are areas that space safety is expected to cover:

- *"Space Safety" should be extended to include the protection of critical space-based services and infrastructure (*e.g. *global navigation systems).*
- *A prerequisite for a safe and sustainable use of space are:*
  - *The control of the space debris population*
  - *International rules for space traffic*

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[11] Looi, M.-K., 2008, *World risks 'scientific apartheid', says top African scientist.* Available at: http://www.scidev.net/global/policy/news/world-risks-scientific-apartheid-says-top-african-.html [Accessed May 23, 2017].

[12] Sgobba, T., 2008, *International Space Safety Space Standard*. TRISMAC Conference 14–16 April 2008.

[13] Roland, H.E., & Moriarty, B., 1990, *System Safety Engineering and Management*, Wiley and Sons, New York.

[14] Sgobba, 2008, *International Space Safety Space Standard.*

The Federal Aviation Administration Office of Commercial Space Transportation has outlined recommended practices for human spaceflight occupants prepared for the much anticipated commercial space flight.

The document is divided into three main sections to take care of the safety/care of astronauts on human spaceflight in the following areas:

- *Astronauts should not experience an environment that would cause a serious injury or fatality.*
- *The level of care for flight crew when performing safety-critical operations should be at the level necessary to perform those operations.*
- *In emergencies, occupants should have a reasonable chance of survival.*[15]

The overall goal of the International Safety standards should incorporate the following:

I. *Ensure that citizens of all nations are equally protected from the risk of overflying rockets, space vehicles and returning spacecraft.*
II. *Ensure that any spacecraft (manned or unmanned) is developed, build and operated according to uniform minimum safety standards which reflect the status of knowledge and the accumulated experience.*
III. *Prevent the risk of collision or interference during transit in the airspace and on-orbit operations.*
IV. *Allow mutual assistance and cooperation in case of emergency.*[16]

5.1.2.3 Resource Mining: Earth and Space

On Earth mining activities involve extracting materials from the lithosphere. The process involves both surface and underground excavations to move the upper layer of soil in order to expose the underlying ores. These raw materials are further refined to get them in their purer form. These are heavy duty that involve huge machineries for extraction, haulage and refinement. Inherent also is the exposure to danger due to collapse of the mine and high temperatures required for smelting/processing. Despite its rough nature, the Earth-based mining has air and gravity available for survival and traction of the workers, respectively.

Space is a harsh environment both for humans and machines. To get to space, astronauts/cosmonauts are expected to ride atop complicated rockets that rely on controlled explosions to attain the tremendous speeds required to achieve orbit. In space, spacecraft and spacesuits must protect their occupants from wild temperature swings, a near perfect vacuum and in some cases poisonous atmospheres and corrosive dusts. People must adjust to “weightlessness”, and they may be exposed to

[15] Federal Aviation Administration, 2014, *Recommended Practices for Human Space Flight Occupant Safety*. Available at: https://www.faa.gov/about/office_org/headquarters_offices/ast/media/Recommended_Practices_for_HSF_Occupant_Safety-Version_1-TC14-0037.pdf [Accessed May 23, 2017].

[16] Sgobba, 2008, *International Space Safety Space Standard*.

potentially harmful doses of radiation. In addition, these space travellers must adjust to the psychological and social conditions of flight.[17]

Most proposals from prospective space mining companies hardly mention safety; carrying out such venture in space, a distance of hundreds of thousands or millions of kilometres from the safety of Earth's environment presents several challenges which could potentially cause harm to the crew and pose a serious problem to would-be regulators. Of concern is the safety of workers/operators, crew and populace during launch, ascent and in-orbit operations to celestial target, on-site operations, back to Earth orbit, re-entry and landing. The risk of injury or death should be removed or minimized in all the phases.

5.1.2.4 Risk and Assessment

Risk on the other hand is defined as "the possibility of loss, injury, disadvantage, or destruction". The role of safety therefore is to minimize risk. The goal is to make sure that every hazard associated with or presented by a system is known and understood fully before it is allowed to operate.[18] All potential hazards posed by the operation to personnel, facilities and other assets must be accounted for by a valid risk assessment. The assessment must be based on accurate data scientific principles and an application of appropriate mathematics. The assessment must be in line with the safety controls that are planned for the mission.[19] It must also be consistent with existing and adopted regulations.

5.1.2.5 Safety Regulations

"Space safety" is a broad term that encompasses human and spacecraft protection from launch to landing, protection of ground and flight services, infrastructure and surrounding buildings and population near the launch site and the protection of space-based services and infrastructure.[20]

There is a growing awareness that space has become much like international sea and airspace, and therefore it is in the interest of everyone to act and operate in

[17] Harrison, A.A., 2002, *Living in Space*, in: Dasch, P. (ed.), Space Sciences, Volume 3: Humans in Space, Macmillan Reference USA, New York, 119–122.

[18] Marshall, Y., 2009, *Introduction to Space Safety*, in: Musgrave, G.E., Larsen, A.M., & Sgobba, T., (eds.), Safety Design for Space Systems, Elsevier Ltd., Oxford, 3.

[19] Sgobba, T., Wilde, P. D., Rongier, I., & Allahdadi, F. A., 2013, *Introduction to Space Operations Safety*, in: Allahdadi, F., Rongier, I. & Wilde, P., (eds.), Safety Design for Space Operations, Elsevier Ltd., Oxford, 7.

[20] Pelton, J.N. & Jakhu, R.S., 2010, *Introduction to space safety regulations and standards*, in: Pelton, J.N. & Jakhu, R.S. (eds.): Space safety regulations and standards, Butterworth-Heinemann, Oxford, xli-xliv.

accordance with increasingly common and harmonized regulations and standards.[21] Ultimately, space safety is in the shared interest of the global community.

The Outer Space Treaty states under Article I that *The exploration and use of outer space, including the Moon and other celestial bodies shall be carried out for the benefit and in the interests of all countries, irrespective of their degree of economic or scientific development, and shall be the province of all mankind.* The idea of "province of all mankind" underlines the ethical duty to protect outer space and the celestial bodies from contamination, but the reverse is equally true. Therefore, safety regulations need to account for both backward and forward contamination.[22]

Furthermore, the OST does not directly deal with safety; however, it offers the following guidance when dealing with contamination. Contamination deals indirectly with the safety of the Earth environment and the protection of its people. The OST states in Article IX that *States Parties to the Treaty shall pursue studies of outer space, including the Moon and other celestial bodies, and conduct exploration of them so as to avoid their harmful contamination and also adverse changes in the environment of the Earth resulting from the introduction of extraterrestrial matter, and where necessary, shall adopt appropriate measures for this purpose.*

Due to the looming threat of contamination, the Committee on Space Research (COSPAR) has created the COSPAR Planetary Protection Policy that is in line with and follows the Outer Space Treaty. COSPAR was founded in 1958, by the International Council for Scientific Unions (ICSU), and is an international organization charged with encouraging international collaboration and information exchange in space research.[23] COSPAR Planetary Protection Policy is not a legally binding treaty. It serves as a set of guidelines on contamination that spacefaring nations should follow when considering space exploration. Within the Policy, there are five categories for "target body/mission-type combinations" with increasing contamination implications: fly-bys, orbiters, landers, probes, non-Earth returns and Earth returns (the highest level of contamination risk due to potential backward contamination). These guidelines have been conceived to attempt keeping both the celestial bodies and Earth safe from contamination from another celestial body.

Asteroid mining and processing will require an intensive power supply system; in this regard, the safety pertaining to the use of nuclear power systems is well covered by the "Principles relevant to the use of Nuclear Power Sources in Outer Space". It is stated that *Recognizing further that the use of nuclear power sources in outer space should be based on a thorough safety assessment, including probabilistic risk analysis, with particular emphasis on reducing the risk of accidental exposure of the public to harmful radiation or radioactive material* and is further iterated through Principle 2 (use of terms), Principle 3 (guidelines and criteria for safe use) and

[21] Pelton, & Jakhu, 2010, *Introduction to space safety regulations and standards*.

[22] Napier, L., & Hettrich, S., 2014, *Interplanetary Contamination and Extraterrestrial Life,* Space Safety Magazine. Available at: http://www.spacesafetymagazine.com/space-exploration/extraterrestrial-life/ [Accessed May 22, 2017].

[23] International Council for Science, n.d., *Space Research (COSPAR)*. Available at: http://www.icsu.org/what-we-do/interdisciplinary-bodies/cospar [Accessed March 2016].

Principle 5 (safety assessment). This prohibits the use of nuclear power systems to be used as weapons of mass destruction and from contaminating outer space environments and requires multiple redundancies to prevent catastrophes from occurring. Special safety controls and consideration will have to be made to monitor the use of nuclear power in near-Earth orbits for possible asteroid-mined processing plants.

The International Organization for Standardization (ISO) is an international standard-setting body composed of representatives from various national standards organizations.[24] Founded on 23 February 1947, the organization promotes worldwide proprietary, industrial and commercial standards. ISO have adapted some safety standards for space systems which can be further developed, the problem with these standards is that they are voluntary, and therefore, these standards need to be incorporated in international laws and brought down to national legislation of all spacefaring nations. They have developed three guidelines, namely, space systems safety requirements (ISO 14620), space systems risk management (ISO 17666) and safety and compatibility of materials (ISO 14624).[25]

The International Association for the Advancement of Space Safety (IAASS) was legally established 16 April 2004 and is a non-profit organization dedicated to furthering international cooperation and scientific advancement in the field of space systems safety. IAASS developed a series of proposals to create an international space safety institute that can be developed into globally accepted space standards, to independently access and evaluate various space systems designs and subsystem performance.[26,27] These proposals are listed above under Space Safety.

There are no safety laws, at an international level, pertaining directly to human space flight; however, this is an issue that would have to be addressed if the mining companies where to consider sending human capital to the asteroid to oversee the mining operation. The missions would have to get human ratings, and additional safety measures would have to be put into place to ensure the safety of the crew. Such measures are carried out at a national level by NASA legislation and ESA legislation; however, there are no national legislations that govern private company activities pertaining to human safety or the safety of civilians on Earth if contamination where to occur.

Generally, a prerequisite for a safe and sustainable use of outer space implies[28]:

- The control of space debris and improved space situational awareness
- International rules for space traffic
- Internationally agreed standards and regulations to achieve compatibility among various space systems and facilities as well as improve safety and reliability

[24] International Organization for Standardization, n.d., *ISO 14620–2:2011: Space systems – Safety requirements – Part 2: Launch site operations*. Available at: https://www.iso.org/standard/46182.html [Accessed May 22, 2017].

[25] Pelton, & Jakhu, 2010, *Introduction to space safety regulations and standards*.

[26] Pelton, & Jakhu, 2010, *Introduction to space safety regulations and standards*.

[27] International Association for the Advancement of Space Safety, 2016, *Welcome to IAASS*. Available at: http://iaass.space-safety.org [Accessed May 23, 2017].

[28] Pelton, & Jakhu, 2010, *Introduction to space safety regulations and standards*.

- Protection of people and facilities on the ground from both direct hazards and indirect environmental effects

"Deflection dilemma" is a term coined in the early 1990s to describe the reciprocity inherent in the capability of mankind to deflect asteroids on a collision path with Earth. In other words, it is human's capability to deflect a passing asteroid to collide with Earth (presumably a collision with a specific target in mind)[29] or more recently for the purposes of asteroid mining. These practices may place otherwise non-threatened people and property, on Earth, at risk.

Furthermore, with asteroid mining in the pipeline the possibility of asteroids colliding with Earth will increase as there are more chances for system failures during the mining operations and all points along the possible impact path are placed in jeopardy.[30] Given that the populations and property put in jeopardy will, in the worst case, extend across international boundaries, the planning and execution of such a mining mission will necessitate international safety measures, controls and coordination to be put in place. Currently no laws, neither national nor international, exist to guide such a situation or the safety of mining operations in general.

As space is becoming more and more privatized, mining opportunities in space are following suit, which poses a severe contamination threat (to civilians on Earth) and a possible threat to the human capital (if needed at the asteroid). A further challenge for contamination prevention is the provision of adequate laws and policies. The Outer Space Treaty is becoming inadequate to the upcoming challenges in this field. Article IX is the only one that discusses contamination and collision and together with the other treaties does not consider private spacefaring entities at all.

Grappling with these daunting issues by an appropriate international body should be undertaken immediately since the development of rational safety policies and measures will be extremely difficult after an impact is announced and an impact path is specified.[31] Developing common standards for space safety – at a national and international level – needs to, and will, continue to improve. These safety regulations and standards will evolve as the need for such measures is increasingly recognized and increased international participation makes them necessary.

5.1.3 Environmental Impact of Asteroid Mining

This section considers the major issues in relation to opportunities and threats presented by space mining.

List of environmental related issues:

(a) Earth carbon footprint of launching and impact of space manufactured fuel

[29] Schweickart, R.L., 2004, *The real deflection dilemma,* Planetary Defense Conference: Protecting Earth from Asteroids, California, 23–26 February.

[30] Schweickart, 2004, *The real deflection dilemma*.

[31] Schweickart, 2004, *The real deflection dilemma*.

(b) Earth carbon footprint impacts of changes in mining behaviour from Earth- to space-based operations
(c) Asteroid environmental impacts
(d) Other celestial body environmental impacts, Moon, Mars, etc.

Issue 1: Launching
From a threat point of view, emissions from rocket launches include carbon dioxide, particulates from the ammonium perchlorate and aluminium solid rocket boosters and hydrochloric acid. Black carbon deposits in upper layers of the atmosphere impacts on the Earth's radiation balance (Ross et al. 2010). So-called "clean" burning liquid fuel rockets require significant amounts of energy (that may be sourced from coal burning) to produce the fuel.

The opportunity is significant; every ton of payload or fuel that can be manufactured in space will have a significant reduction in the fuel requirements to launch from the surface of the Earth. The saving will be experienced right through the fuel production chain significantly reducing the environmental impact.

Issue 2: Change in Mining Behaviours
The demand for rare-Earth metals has increased significantly since the mid-1980s with increasing demand-driven electronic manufacturing (computer memory, DVDs, rechargeable batteries, cell phones, catalytic converters, magnets and fluorescent lighting) having significant environmental impact due to the low yield of the elements through current mining practices.[32]

The opportunity offered by space mining would be the sustainable and less environmentally destructive (well from Earth's point of view) extraction process of these valuable elements.

Issue 3: Asteroid Environment
The threat is clear: that since the celestial body is not Earth, the impacts on human beings of poor mining practice will be very little. This leaves the way open for a destructive approach to mining.

Issue 4: Other Celestial Body Environment
Similar to issue 3 except that humankind may now have more of an interest in a large (particularly) habitable celestial body remaining unviolated/unpolluted. The opportunity is to put down good agreements/regulations that ensure the sustainable use of outer space for the benefit of all humankind.

[32] King, H., 2016, REE – Rare Earth Elements and their Uses. Available at: http://geology.com/articles/rare-earth-elements/ [Accessed May 19, 2017].

5.1.3.1 Environmental Effects, Impacts and Outcomes of Space Mining

Asteroid mining is the exploitation of raw materials from asteroids and other minor planets.[33] Minerals and volatiles could be mined from an asteroid or spent comet and then used for in situ resource utilization (construction materials and propellant) or taken back to Earth. Specifically, platinum and cobalt, for example, can be mined from asteroids and sent for Earth's utilization or can be used to build solar power satellites and space habitats, whilst water available from ice can be used to refuel orbiting propellant depot. Some of these include gold, iridium, silver, osmium, palladium, platinum, rhodium and tungsten for transport back to Earth; iron, cobalt, manganese, molybdenum, nickel, aluminium and titanium for construction; water and oxygen to sustain astronauts; as well as hydrogen, ammonia and oxygen for use as rocket propellant.

No doubt, using space materials to develop space-related utilization like propellant, tankage, radiation shielding and other massive components of space infrastructure can lead to significant reduction in space mission cost and space energy utilization.

In the world of today, terrestrial mining is still the main raw material exploitation due to the high cost of space transportation. Space mining, both now and in future consideration, is borne out of the increasing scarcity of Earth resources where the actual[34] qualities of graded ores of many minerals are on the decline. The reason is due to the ever-increasing consumption of these industrial minerals by both developed and developing economies, with facts showing entire exhaustion in the Earth reserve by 50–60 years.

One consequence of asteroid exploitation is asteroid strike, when asteroids collide with other planetary bodies in the near-Earth object (NEO) causing measurable effects.[35] Although the most commonly recorded in the planetary systems have had minimal impact due to the smaller sizes of such impacting asteroids. When such larger asteroids impact terrestrial planets like Earth, significant and biospheric consequences result. Impact craters and structures are examples of solar system landforms resulting from planetary strikes. Other consequence can be mass extinction like the Chicxulub impact which occurred about 66 million years ago and was believed to be the cause of Cretaceous-Paleogene extinction 3. Historically, hundreds of impacts have been reported with some events causing injuries, destruction of properties and death. Others include localized consequences.

The Tunguska event[36] in Siberia, Russia, in 1908 was also an example. B612 Foundation, a non-governmental organization with the headquarters in the USA, is

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[33] BBC News, 2016, *Falling oil prices: How are countries affected?* Available at: http://www.bbc.com/news/world-35345874 [Accessed May 23, 2017].

[34] Calvo, G., Mudd, G., Valero, Al., & Valero, An., 2016, *Decreasing Ore Grades in Global Metallic Mining: A Theoretical Issue or a Global Reality?,* Resources, 5(4), 36–49.

[35] Lewis, 1996, *Mining the Sky: Untold Riches from the Asteroids, Comets, and Planets*.

[36] Ol'khovatov, A.Yu., 2003, *Geographical Circumstances of the 1908 Tunguska Event in Siberia, Russia*, Earth, Moon and Planets, 93(3), 163–73.

conducting an investigation which can help to identify big and threatening asteroids by cataloguing 90% of those with diameters larger than 140 m.

Mining asteroids require significant amount of heat energy utilization through all the extracting processes. The effect of this is the emission of considerable amount of heat energy from the sun to the surrounding planetary bodies. And since there is no significant atmosphere in the space to trap the volume of heat energy emitted, from mining exploration, it is then a fact that one space adventurer would need to consider the consequence of heat in the balance of temperature range in the space environment. Asteroid mining proposal is far just beyond scientific and research-oriented mission; the long-time goal is to be a huge quantifiable mission sufficient enough to bring financial profits to justify the huge investment. Extensive mining efforts on the Moon, however, could scar its surface irreversibly. The Lunar Base Working Group in Alamos National Laboratory (1984) stated that mining of the lunar surface is an area of potential environmental concerns. The following were enumerated as the potential effects of environmental impacts: increased atmospheric pressure which could change atmospheric compositions and affect astronomical observations. It can lead to increased very low radio frequency background through satellites communications which can affect the use of the far side of the Moon for radio telescope.

Studies of the potential use of nonterrestrial materials could have far-reaching implications for the environment low Earth orbit and the lunar surface, in terms of both use and the prevention of possible contamination. A need is clearly emerging for some of environmental assessment and management to determine what to use space or planetary surfaces for and how to do it. Most lunar scientific activities require that the unique lunar environment be preserved. It is evident therefore that lunar operational mining will affect this environment in adverse ways.

In conclusion, numerous components of mining on the Moon must be environmentally assessed: the scale of the mining operation, its associated development and its technological features. The following factors affect the scale of mining significantly: ore quality, size of ore body, availability of energy, cost of operation and type of operation.[37]

The formation of positive attitude and values concerning the environment of space, as the basis for assuming stewardship role, is becoming increasingly important as many nations begin their journeys into space. A strong emphasis should be placed on fostering an international space environmental ethics.

[37] Tangum, R., 1992, *Future Space Development Scenarios: Environmental Considerations*, in: McKay, M.F., McKay, D.S., & Duke, M.B. (eds.), Space Resources: Social Concerns, NASA, Washington D.C., 220–30.

5.2 The Educational, Economic and Political Effects and Outcomes of Resources Extraction and Utilization

5.2.1 Educational Aspects Associated with Asteroid Mining

The whole idea of space mining came into existence because someone thought about it, and where did these ideas came from, probably from someone who had knowledge of it, and the principle place to gather knowledge is through education, as it is the prime phase to expose us to the wonders around us.

Asteroid mining is a perfect example for South Africa as a technological demonstration. Many South African youngsters have always dreamt and wandered what is in space; this advancement will be an inspiring motivation for youngsters to pursue STEM studies. Furthermore, on top of hoping they could be the astro-miners or the talented engineers who designed and built the asteroid mining spacecraft, STEM education will certainly boost the economy and provide the technical talent South Africa needs. The Apollo missions inspired a whole generation of kids who wanted to grow up to be astronauts, rocket scientists, and engineers. The asteroid mining mission to near-Earth asteroid will again inspire a whole new South African generation to reach for the outer boundaries of the Earth (Fig. 5.1).

On top of futuristic technological inventions, it is a philosophy that drives the eagerness of every individual to open up their mind to explore limitless ideas. Exploration beyond our planet certainly intrigues our imagination. Limitless ideas and thoughts will ensure a very exciting future. Investing in philosophical studies

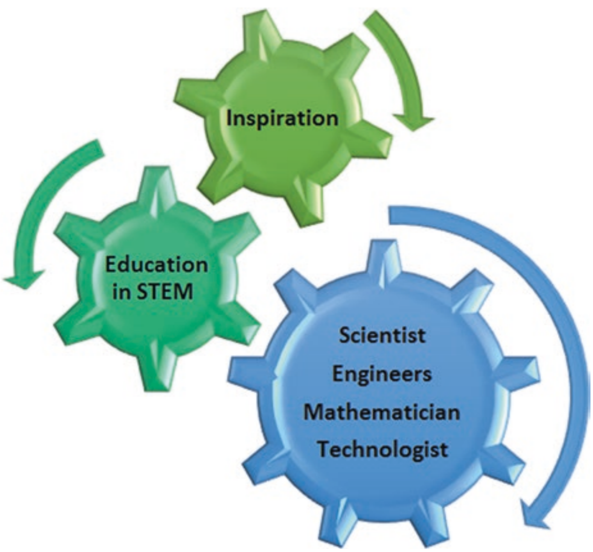


Fig. 5.1 Asteroid mining: inspired scientists, engineers, mathematicians and technologists in South Africa

would definitely bring out talented thinkers who can judge on the societal benefits of outer space exploration. It is humanity's number one global moral imperative to provide the educational and technological resources, as well as develop the overall mindset, for the advancement of space exploration and utilization.

History teaches us that when the first human explorer went across the vast ocean, arguments, wars on monopolizing resources, territory appropriation, and mass massacres all begin with a lack of common acknowledgement of a legal frame. It is essential to construct a legal framework that will not repeat the same tragedies that occurred in the past. In case of asteroid mining, a legal frame must be constructed that will ensure anti-appropriation, anti-space war and anti-space resource monopoly. The entire above mentioned can be further achieved by involving young South African lawyers who could come up with different legal perspectives on the new and to-be-explored environment (Fig. 5.2).

In the bigger picture, regarding education, whether it is space travel, living in space, studying space and other planets or asteroid mining, it uses all aspects of science, philosophy and law. It is the young engineers, lawyers, and scientists; technologists with their entrepreneurial, energetic, imaginative perspective that could bring a tremendous change in further space exploration and utilization.

Education is vital to ensuring the long-term viability and well-being of South African technological, scientific and political advancement, as well as for providing a new generation of well-qualified engineers, technicians, scientists, and policymakers

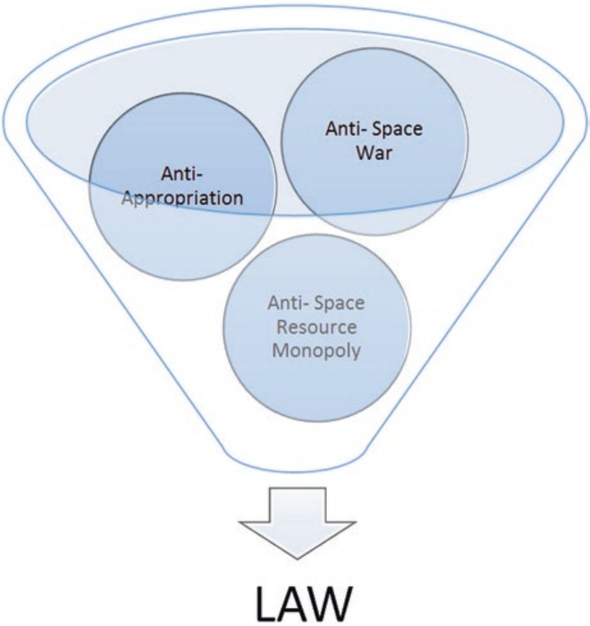
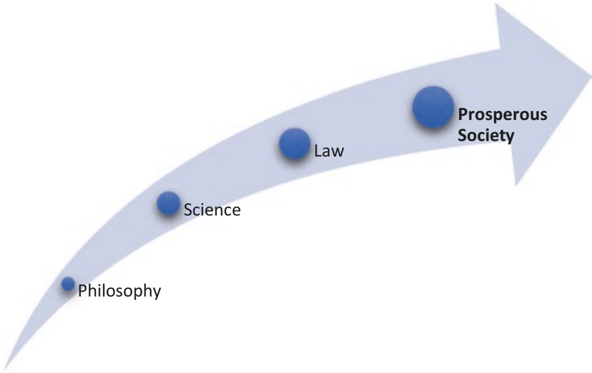


Fig. 5.2 The 3As (anti-appropriation, anti-space war and anti-space resource monopoly) should guide the formation of new laws on space mining

Fig. 5.3 Starting from philosophy to the motivation of pursuing science to formation of new space law, all three aspects add up to a prosperous society in South Africa



which can improve upon the achievements of the current generation of space engineers, scientists, and political leaders. The space industry is now a big business. It is no longer a matter of space travel. It's also about an industry that has enormous potential future growth for South Africa which must be fuelled by education. After all, scientific, political, philosophical, technological knowledge, skills and artefacts "invade" all realms of life in modern society (Fig. 5.3).

5.2.2 *The Economic Effect on Space Resource Mining*

Space mining can be of great economic importance; it can become the future generation's economic boom, like the oil boom of the 1940s. Though space mining is capital intensive, it can yield an extensive return in terms of profit in the long run. An estimated investment of $2.6 Billion USD, ignoring the cost in processing the extraction of the materials from the asteroid, on a 500-ton asteroid in LEO can yield returns of about $25–50 billion from just a 30-m-long platinum-rich asteroid as stated by Planetary Resources (Fig. 5.4).

On deep-sea mining, according to the *Marine Technology Society Journal*:

> A typical area of 75,000 sq km with an estimated nodule resource of >200 mi t., is expected to yield about 54 million tonnes of metals (Mn+Ni+Cu+Co) and the gross in-place value of the metals is estimated to be ~$ 21–42 billion (depending upon the annual rate of mining) in 20 years life span of a mine-site. The decision on the timing to resume mining of these deposits will be based on the prevalent metal prices and rate of returns on the estimated investment of $ 1.95 billion as capital expenditure and $ 9 billion as operating expenditure for a single deep-sea mining venture.[38]

Comparing the cost of operation and the return in revenue between space mining on platinum-rich asteroid and deep-sea mining on (Mn + Ni + Cu + Co), you will find out that the return in revenue for space mining within a period of 10 years and

[38] Sharma, R., 2011, *Deep-Sea Mining: Economic, Technical, Technological, and Environmental Considerations for Sustainable Development*, Marine Technology Society Journal, 45 (5), 28–41.

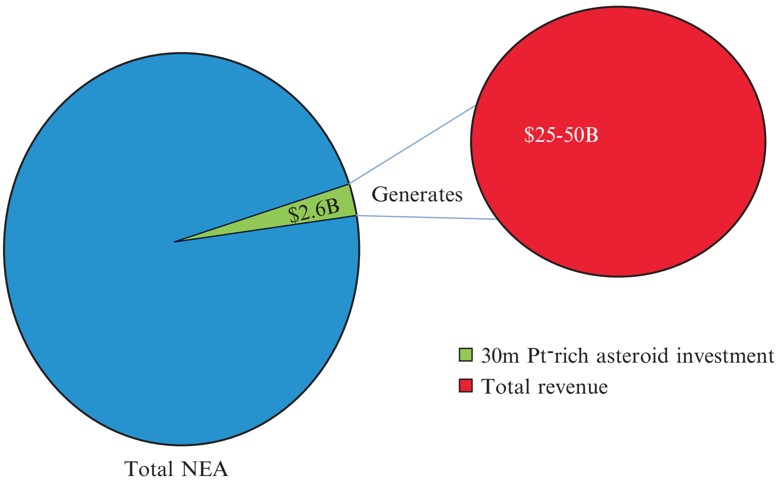


Fig. 5.4 Estimated returns from asteroid mining

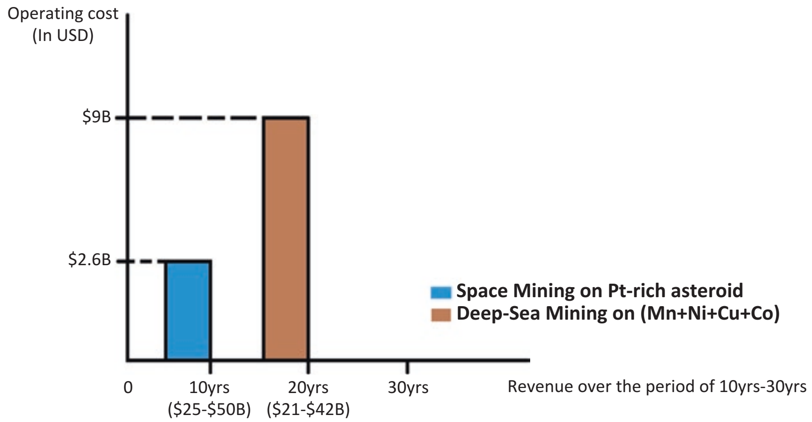


Fig. 5.5 Comparison between deep-sea mining and space mining on Pt-rich asteroid

a relatively smaller investment is almost the same, compared with the deep-sea mining. This is expressed in Fig. 5.2 (Fig. 5.5).

The major issue on the economic effect of space is if it is feasible. A feasibility analysis is carried out to determine the financial viability, risk, and robustness of a project. If the net present value (NPV) of the project is at least zero or positive, and the internal rate of return (IRR) meets the company's barrier rate, such a project is accepted. If not, the project is unacceptable. As it is, the feasibility of space mining is still uncertain (Fig. 5.6).

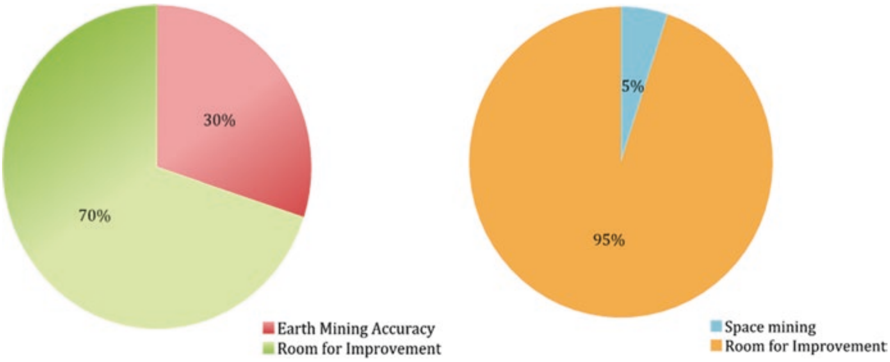


Fig. 5.6 Earth/space mining accuracy

The success of a mining operation lies on the accuracy of a pre-feasible study. According to *infomine.com*, the accuracy of studies of traditional Earth mining is about 20%–30%.[39]

With such low-accuracy pre-feasibility studies carried out on Earth mining, it's less likely to get better with space resource mining, which should be 0%–5% in the short run. Furthermore, with the said vast amount of platinum in outer space, what will happen to the Earth-bound price of platinum if we succeeded in getting these materials down to Earth? It will obviously lower the price and increase the supply chain, therefore shifting the supply curve to the right, and this will probably cause a downshift in the platinum market, as it is now with the oil market (Fig. 5.7).

In conclusion, the economic effect of outer space in real-time or in the short run is not practical and will take a massive amount of capital budget to embark on, with an uncertain output. Accordingly, South Africa is the highest platinum-producing country in the world,[40] so bringing more platinum from space down to Earth will certainly affect the supply market as well as the price, which will certainly reduce the GDP of the country since platinum is one of the major sources of economic revenue. In the short run, more focus should be on the extraction of water (H_2O), since it is one of the most important resources in space. According to planetaryresources.com, "Water is more than the 'oil of space'". In orbit and beyond, it can play roles like hydrating astronauts, providing oxygen for life support, and serving as a shield against harmful radiation in space".[41]

[39] Kumar, A., *Feasibility Studies*. Available at: http://technology.infomine.com/reviews/FeasibilityStudies/welcome.asp?view=full [Accessed May 31, 2017].

[40] Van Vuuren, A.J., 2015, *The World's Third-Biggest Platinum Miner Just Announced That It's Cutting Production*, Bloomberg. Available at: http://www.bloomberg.com/news/articles/2015-07-24/the-world-s-third-biggest-platinum-miner-just-announced-that-it-s-cutting-production [Accessed May 23, 2017].

[41] Planetary Resources, n.d., *Asteroid Composition*. Available at: http://www.planetaryresources.com/asteroids/#asteroids-types-of-asteroids [Accessed May 23, 2017].

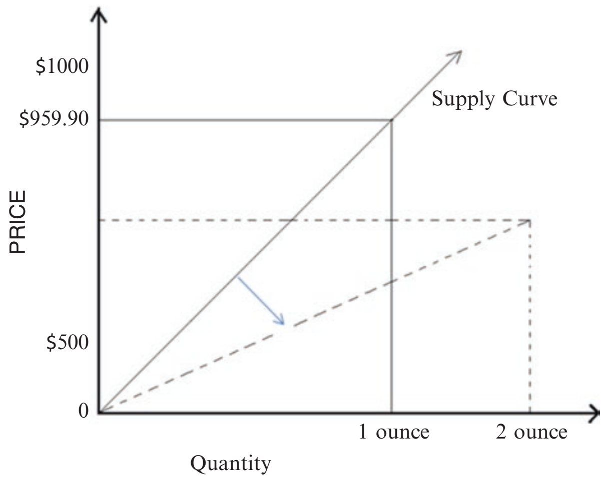


Fig. 5.7 Estimated shift in the supply curve of platinum in South Africa due to increase in quantity

Yes, provisions should be made in terms of keeping trends with the space movement, like creating programmes for space mining missions in the near future and implementing legal policies that will attract investors in this market. But embarking on a space mining mission now as a country will not be economically viable.

5.2.2.1 Future Economic Perspectives

This however does not rule out the possibility of space resource mining becoming a reality in the future and the long-term impact it will have. Trade of minerals within the space environment will operate on the principle of scarcity and abundance, thus a market will only exist where there is a demand. The return of many resources to Earth will not be economically feasible, as asteroid resources such as water, oxygen, and rare-Earth elements are available cheaply in vast quantities terrestrially. On the other hand, water and oxygen are scarce in space and paramount to further development and expansion. The platinum group metals (PGMs) however may deviate from this as current terrestrial monopoly and high prices limit the overall demand. From here we see two distinct customer markets appearing: the limited terrestrial market and growing space-based market.[42,43]

Long-term mining in space will thus only flourish once human activity and presence in orbit greatly expands, and a commercial space economy forms. This

[42] Government of South Africa, 2014, *Mineral Resources. South Africa Yearbook 2014/15*. Available at: http://www.gcis.gov.za/sites/www.gcis.gov.za/files/MineralResources.pdf [Accessed May 23, 2017].

[43] Cohen, 2013, *Robotic asteroid prospector (RAP) staged from L1: start of the deep space economy.*

commercial shift in space infrastructure has already begun as can been seen in the sale of the Russian MIR space station to a private US entity.[44] The future development of large-scale infrastructure such as manufacturing facilities, space stations, power plants and colonies will require enormous amounts of construction material, propellant, and life-sustaining resources. The supply of these resources will only be economically feasible if sourced from space itself, as the cost of launch from the surface of the Earth for these materials is roughly $10,000 per kg. Companies like SpaceX and Blue Origin are trying to greatly reduce these launch costs and if successful will create competition with space mining industries for the supply of abundant resources to build the orbital space infrastructure of the future.[45]

5.2.2.2 Long-Term Scenarios in the South African Economy

South Africa has a long history in the mining industry which initiated the country's industrial revolution and sustained the economy for over a century. South Africa has the largest reserves of gold, coal and PGMs in the world, along with a deep mineral wealth of diamonds, chrome, vanadium, titanium, manganese and much more. South African gold mines produced over 50% of the world output of gold in the early 1980s, constituting 40–50% of the country's exports. The taxation of gold thus formed a large portion of the country's income; in the period from 1981 to 1983, gold tax centred around 16.7% of the total governmental revenue. Mining remains the largest industry in the South African economic sector, with 419,219 employees and R241 345 million in sales in December 2009, and Fig. 5.8 below depicts the

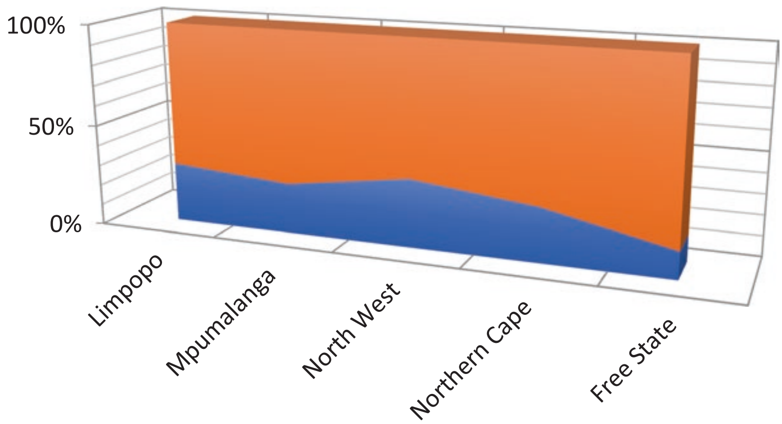


Fig. 5.8 GDP percentage contributions for the five largest mining provinces in South Africa

[44] Blair, 2000, *The Role of Near-Earth Asteroids in Long-Term Platinum Supply*.

[45] Sonter, M., 2006, *Asteroid Mining: Key to the Space Economy*. Available at: http://spsaero.us/Key_ComSpace_Articles/LibGen/LIB-077_Asteroid_Mining-Key_to_the_Space_Economy.pdf [Accessed May 23, 2017].

current mining contribution to the GDP of the five largest mining provinces in South Africa.[46,47,48]

If South Africa adopts a pro-space mining legislature and it becomes a reality, the country could benefit in a similar manner. Taxation of products collected by space mining companies under the jurisdiction of South Africa could support the country's revenue income. Furthermore, with foreign investment and new companies being established in the Republic, more jobs will become available, and incoming capital will be spent on people and material within the country. These additional revenue income sources will strengthen the economy in the long term and reduce the current reliance on our terrestrial mineral reserves.

5.2.2.3 The Case of the Platinum Group Metals

The platinum group metals (PGMs) as mentioned before are a defining aspect of the South African mining industry and introduction of a new extraterrestrial supply will have multiple effects. The current demand for platinum is split between industrial uses such as autocatalysts and electronics and precious metal uses in jewellery and bullion coins. It is also stockpiled as a strategic resource for military and aerospace applications by countries like the USA. However, should the quantity greatly increase and the price fall as a result of external supply from space mining, many other industries will begin using platinum in their processes, and the global demand will increase. At the current demand and growth levels, the South African platinum reserves are expected to become exhausted within 250 years as seen in Fig. 5.9.[49] A significant increase in demand will greatly reduce the years to depletion and require further development of the terrestrial mining industry to meet demands and maintain its mineral dominated economic sector.

The expanded use and demand of platinum as a result of space resource mining may cause significant growth in other markets and industries, but as South Africa currently possesses minimal manufacturing capabilities related to platinum use, we are not positioned to gain. This situation will ultimately depend on the ability of the space mining industry to maintain supply and deliver timeously. If not the case, the existing platinum producers can drive down the price prior to a shipment's arrival, causing PGMs delivery to Earth to lose its economic feasibility.[50]

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[46] Statistics South Africa, 2012, *National Accounts: Mineral Accounts for South Africa: 1980–2009*. Available at: http://www.statssa.gov.za/publications/D04052/D040522009.pdf [Accessed May 23, 2017].

[47] Statistics Times, 2016, *Projected GDP Ranking (2016–2020)*. Available at: http://statisticstimes.com/economy/projected-world-gdp-ranking.php [Accessed May 23, 2017].

[48] Wilson, F., 2001, *Minerals and migrants: how the mining industry has shaped South Africa,* Daedalus, 130(1), 99–121.

[49] Statistics South Africa, 2012, *National Accounts: Mineral Accounts for South Africa: 1980–2009*.

[50] Blair, 2000, *The Role of Near-Earth Asteroids in Long-Term Platinum Supply*.

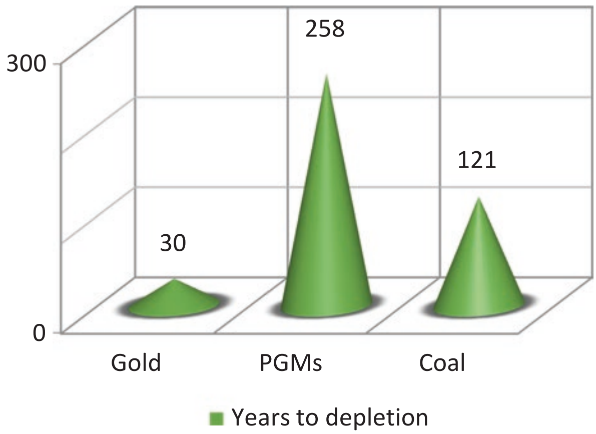

Fig. 5.9 Years to depletion for gold, coal and PGMs as of 2009

The resources of Earth are finite and with future development and expansion into space, even more will be needed. South Africa's economy is largely dependent on these resources and their depletion will leave us crutch-less. Space mining is an eventuality, whether in the short or long term, if we are to build super structures in orbit and populate the stars. We are in a position to not be taken by surprise; we have the opportunity to create laws and policies now that will transform us in the coming future. We can remove our historic crutches, the dependence on our resources, and expand into new industrial and manufacturing areas and bring new investment to our lands.

5.2.3 *Effects and Outcomes of Space Resource Mining on the US and South African Politics*

Space resource mining could potentially impact the political scene in the USA as well as in South Africa. This section reflects on the potential impact of such a venture from a political perspective. To do so, the political impact of the "curse of oil"[51] in developed countries will be used as analogy to understand the potential impact on the US political scene. In addition, since South Africa's economy relies on mining[52], the political impact, if this pillar of the economy is no longer standing, will also be investigated.

[51] Venables, A.J., 2016, *Using Natural Resources for Development: Why Has It Proven So Difficult?*, The Journal of Economic Perspectives, 30(1), 161–84.

[52] Davies, R., 2015, *Mining "still a key pillar for SA economy"*. Available at: http://www.southafrica.info/news/mining-090215.htm#.VvIZqOJ97X4 [Accessed May 23, 2017].

5.2.3.1 The Impact on the US Political Scene

The "curse of oil" is a situation which might occur when countries are able to exploit a large pool of natural, non-renewable resources, resulting in a negative impact on their economic growth and democracy.[53] Whilst this situation is not bound to happen, it has impacted several countries both in the developing and in the developed world (e.g. Nigeria). Whilst having a negative impact on the economy, the "curse of oil" can also impact the political scene in a country.

If the USA is able to successfully exploit minerals from space resources (e.g. platinum), it would be equivalent to them having access to a large pool of natural resources (e.g. oil) on Earth, which they could exploit and export to the rest of the world. In that case, the USA runs the risk of being impacted by the "curse of oil" if no proper measures are put in place to prevent it, leading to further consequences on their political scene. For example, it has been shown that money from natural resources often directly flows to powerful players in a country (e.g. the government itself). As a result, there would no longer be a need for the US government to raise revenues through taxes. Furthermore, those who are not being taxed would no longer have incentives to hold the government accountable.[54]

In African countries, the "curse of oil" has often lead to civil war. In a given 5-year period, African countries with non-renewable, natural resources have more chances of falling into civil war than those who don't have such resources.[55] However, it might be argued that the probability of this happening in the USA is lower since the country has stronger democratic and governmental institutions than African countries.

5.2.3.2 The Impact on the South African Political Scene

Similarly, to other African countries, South Africa's economy is highly dependent on the export of mineral to the rest of the world.[56] In the event of US space resource mining being successful, the world might be flooded with space minerals, resulting in a drop in the price of minerals due to supply over demand. This might have drastic consequences for the South African economy and consequently the political scene.

It might be anticipated that the lowering of South African mineral exports would lead to unemployment, discontent and food and basic shortages in the country, which might further lead to people voting for the opposition. A similar situation is currently being witnessed in Venezuela, whose oil exports accounted for about 95%

[53] Venables, 2016, *Using Natural Resources for Development: Why Has It Proven So Difficult?*

[54] The Economist, 2005, *The paradox of plenty*. Available at: http://www.economist.com/node/5323394 [Accessed May 23, 2017].

[55] Collier, P., Hoeffler, A., & Rohner, D., 2009, *Beyond greed and grievance: feasibility and civil war*, Oxford Economic Papers, 61(1), 1–27.

[56] BBC News, 2016, *Falling oil prices: How are countries being affected.*

of the revenue of the country. With the current drop in oil prices, the Venezuela's revenue has dropped by 60%.

5.2.3.3 Bird's-Eye View on Political Consequences

Space mining which is mainly related to asteroid mining is the exploitation of raw materials from asteroids and other minor planets, including near-Earth objects. Minerals and volatiles could be mined from an asteroid or spent comet and then used in space for in situ utilization (e.g. construction materials and rocket propellant) or taken back to Earth. These include gold, iridium, silver, osmium, palladium, platinum, rhenium, rhodium, ruthenium and tungsten for transport back to Earth; iron, cobalt, manganese, molybdenum, nickel, aluminium and titanium for construction; water and oxygen to sustain astronauts; as well as hydrogen, ammonia and oxygen for use as rocket propellant. This acquisition of resources will have political impact in the nations where these resources will acquire and on the global as a whole, since the space belongs to mankind regardless of the nation.

Politically it has been observed that the discovery of massive natural resources have dire political impact in various nations. One can say that the same will apply to the resources that would be mined in space. The conflicts and the fights will be experienced here on Earth and not only to the nation that does the mining only but globally. Besides the negative political impact, one can also see some economic development that can come with the resources from the space mining and that makes it a viable idea to still pursue with the space mining. However, international policies and legislation that can be followed by all nations should be put in place before the space mining is implemented to ensure that there will be fairness in the consumption of the space resources.

5.3 Potential Regulatory Options and a Pathway to Develop Practicable Regulations for Space Resource Extraction and Utilization

Several models exist from which to consider for regulating space resource extraction and utilization. These are considered below and explained for how such a regulatory framework could be developed among policymakers.

5.3.1 The International Space Treaties and Moon Agreement Model

There are various ways that space activities could be regulated; one regulatory model is the use of treaties. As mentioned there are five UN treaties relating to outer space, the main article being the Outer Space Treaty with subsequent treaties elaborating on different aspects of the main treaty. As the treaties are based in international law, they tend to be written in a broad language; as a result they do not tend to very specific issues. Whilst the Outer Space Treaty incorporated issues such as national appropriation of celestial bodies, the peaceful use of outer space, freedom of use of outer space, liability of an object in outer space, registration of space objects and providing assistance in outer space, further treaties were needed to specify more the legal application of these requirements. Consequently, the Rescue Agreement, Liability Convention, Registration Convention and the Moon Agreement treaties were developed.

The Moon Agreement addresses the need to regulate the use of space resources including the Moon and other celestial bodies. In accordance with the Outer Space Treaty, the Moon Agreement elaborates on how space resources should be managed. Article 11 of the Moon Agreement states that the states party to the agreement will establish an international body to govern the exploitation of natural resources in space.[57] In order for this governing body to function effectively, the states parties will also be required to share any information obtained through their exploration of the resources on the Moon. Noting the responsibilities of the Outer Space Treaty, the governing body established under the Moon Agreement would be responsible for:

(a) Safety regarding development of natural resources of the Moon
(b) Management of the Moon's resources
(c) Expanding the opportunities in use of those resources
(d) Equitable sharing by all states parties in the benefits derived from those resources

The Moon Agreement also further expands on the appropriation of space objects defined in the Outer Space Treaty to exclude ownership of extraterrestrial property by any international or intergovernmental or non-governmental organization, national organization or non-governmental entity or of any private person.[58] However, as with the Outer Space Treaty, this only applies to objects in situ so this would not prevent states engaging in resource extraction. Provision is also made in the treaty in Article 6 for mineral extraction, where it states that states parties have

[57] United Nations, 1967, *Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies.*

[58] Listner, M., 2011, *The Moon Treaty: failed international law or waiting in the shadows?*, The Space Review. Available at: http://www.thespacereview.com/article/1954/1 [Accessed May 23, 2017]; Froehlich, A., 2017, *Utilization – Consumption – Appropriation: Asteroid mining is in the pipeline*, ZLW, 2, 268–281.

Table 5.1 Number of countries to ratify the five UN space treaties (United Nations 2017)

OST	Rescue agreement	Liability convention	Registration convention	Moon agreement
105	95	94	63	17

United Nations, 2017, *Status of International Agreements relating to activities in outer space as at 1 January 2017,* United Nations, New York

the right to collect and remove Moon samples in a quantity appropriate for the support of the mission.[59]

The Moon Agreement also encourages cooperation by requiring all vehicles, equipment and installation on the Moon to be open to other parties; it also makes provision for such parties to only allow entrance to their facilities as they deem safe and appropriate. Further to this, Article 12 states that ownership of space equipment, facilities, stations and installations shall not be affected by their presence on the Moon and they will still be monitored under the jurisdiction of their particular states.

Although it is not explicit, there is an opportunity for states parties to be taxed as Article 4 of the Moon treaty states that exploration and use of space resources will be for the benefit of all mankind acknowledging the need to promote underdeveloped countries with regard to social and economic progress regardless of their scientific development. The states parties will also be required to share any information obtained through their exploration of the resources on the Moon in order for the regime to effectively assess the equitable distribution and management of space resources.[60]

Given the current engagement of the private sector in space activities, consideration should be given to the nature of private industries. These factors such as taxation and compulsory sharing of information could be seen as deterrents for the private sector, and this could detract countries wishing to promote this sector from ratifying the treaty. As noted in Table 2.1, there has been a considerable drop in countries ratifying the treaties. These additional treaties contain more particular requirements of states party to the treaties; and as a result some states have been less inclined to ratify them. The lack of ratifications of the Moon Agreement could be attributed to the introduction of an international governing body and specific details concerning ownership of the Moon (Table 5.1).[61]

By ratifying the Moon Agreement, states are relinquishing some control over the natural resources in space, and they will be regulated by an international regime. The methods to regulate and enforce these obligations have not been stated in the Moon Treaty.

[59] United Nations Office for Outer Space Affairs, 2008, *United Nations Treaties and Principles on Outer Space and related General Assembly resolutions*.

[60] United Nations Office for Outer Space Affairs, 2008, *United Nations Treaties and Principles on Outer Space and related General Assembly resolutions*.

[61] United Nations Office for Outer Space Affairs, 2008, *United Nations Treaties and Principles on Outer Space and related General Assembly resolutions*.

The process for developing and adopting treaties is also slow and arduous. This is supported by the general trend in space regulations that focus more on nonbinding principles and resolutions to which countries may tailor their own national laws.

5.3.2 Common Heritage of Mankind Model

Rüdiger Wolfrum[62] puts forward the view that it is striking that instead of "all states", "mankind" has been named the beneficiary in the principle of common heritage in relation to seabed activities and, of course, outer space as well. The Convention on the Law of the Sea mentions as potential beneficiaries of the utilization of the sea also peoples who have not attained full independence or other self-governing status.

The adoption of the term "mankind" from the Outer Space Treaty taken together with the term "heritage" at least indicates that the interests of future generations have to be respected in making use of the seabed. To accept the common heritage principle to be part of international customary law, the following preconditions have to be met: The content of the principle must be distinct enough so as to enable it to be part of the general corpus of international law, and respective state practice accompanied by evidence of opinio juris must exist. Custom must finally be so widespread that it can be considered as having been generally accepted.[63]

The common heritage principle has not only been accepted as an essential element of the Convention on the Law of the Sea, from where it found its way into the national legislation relating to seabed activities, but was also introduced into the outer space regime and, to a lesser degree, into the legal framework for the protection of the Antarctic environment.

Though the existence of differences between the regime governing the utilization of the Moon and the regime with respect to deep seabed mining should not be denied, it has to be strongly emphasized that both are governed by the same basic elements. Thus, it can be summarized that during the negotiations on the law of the sea and on outer space the common heritage principle has, as a leading principle to govern the use of areas beyond national jurisdiction, been specified as to its basic content. Practice has a norm-creating effect so that the particular conduct is obligatory if it is accompanied by statements on the part of states that this particular conduct is mandatory.

Perhaps it should be mentioned too that the phrase of the cultural common heritage of mankind has been accepted legally. Leaving aside these recent developments, it has to be stated that the common heritage principle has been invoked whenever the distribution or protection of areas or resources are at stake which lie outside the limits of national jurisdiction. Accordingly, in evaluating this principle

[62] Wolfrum, R., 1983, *The Principle of the Common Heritage of Mankind*, Heidelberg Journal of International Law, 43(2), 312–27.

[63] Wolfrum, 1983, *The Principle of the Common Heritage of Mankind.*

it has to be taken into consideration that it only gained legal significance in connection with the establishment of an international administration for areas open to the use of all nations.[64]

It must be stated that in all other iterations of international body and common heritage principle models of authority, there has not been an across-the-board panacea. Drawing from the Convention on the Law of the Sea, mankind may need to, in the case of outer space, be represented by an outer space authority, and it would have an elected natural person occupying the role of secretary general. The practical route would be establishment of an international organization empowered with a resource-orientated jurisdiction underpinned by the declaration of mankind, in its entirety, to be the beneficiary of outer space and its resources. Numerous debates that prevailed with regard to the Seabed Convention were whether there should be a moratorium on activities or whether there should be assurance of equal participation or a compensatory system in which those with capacity participate unbridled, but as part of that, they ensure equitable indirect gain even by those who lack the means to participate directly.

In current terrestrial mineral resource mining, the operations, revenues and benefits are distributed across international boundaries owing much of those activities being dominated by multinational entities. There exist frameworks of beneficiation, and most recently there has been established in development regions such as in the Southern African Development Community, the gradual harmonization of mineral policies through standardization and policy alignment.

The harmonized policy environment is expected to reduce detrimental competition among the member states and lead to the sharing of capacities and competencies through a liberal movement of economic factors, including capital and labour, across the subregion.[65]

Overall, the principle naturally leads to their needing to be a levy, royalty, legacy fund mechanism that will be part of the mix of solutions in ensuring all mankind benefits even from the activities by few entities that might have better financial means, technology and data to pursue outer space resource utilization.

To enhance practicability, the existing structure of the international community of states, which leaves the administration of the common heritage to the individual states, can prevail. Just as all states are ultimately responsible for their national entities, governmental and non-governmental, the states then act not on their own but in the capacity of an organ of the international community. Also, this not only ensues accountability, but it empowers states which would of course be subject to the outer space authority so that in the end, there is no "tragedy of the commons" scenario when things go wrong. Owing to the financial and technical implications of outer space activities and by extension resource utilization, not all states could participate readily.

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[64] Wolfrum, 1983, *The Principle of the Common Heritage of Mankind.*

[65] United Nations Economic Commission for Africa, 2004, *Harmonization of Mining policies, standards, legislative and regulatory frameworks in southern Africa*, United Nations, Addis Ababa.

5.3.2.1 Authorization and Licencing

Authorization and monitoring of activities will fall on the organs of the international community, the states, and this will be for governmental and non-governmental entities that endeavour to operate in outer space. Licencing will follow the existent legislation as in the form of South African Space Affairs Act[66] where each state serves such a function but all licences are correlated and feed into a central data system of the international community in this context.

It is interesting that Wolfrum,[67] on the issue of control and jurisdiction and by extension implications of resources entering jurisdictions they previously were not in; the Seabed Authority is bound to enter commodity agreements which are used to stabilize the trade on commodities.

Secondly, the Convention provides for the limitation of production of minerals derived from the seabed so that seabed mining may only produce a part of the increase in world demand. Thirdly, those states which suffer adverse effects in their export earning or economies caused by activities in the area will receive compensation. The basic idea underlying this system may be described as follows: As the deep seabed is the common heritage of mankind and as this area is bound to be used primarily in the interest of developing countries, it must be assured that the use of the seabed area will not cause adverse effects to those supposed to be the privileged beneficiaries.[68] These arguments do not take into account that cheap commodities may be much more in the interest of the majority of the developing countries than the maintenance of an artificial high price ceiling. Besides, the demand that the resources of the seabed should be used for the benefit of mankind involves their utilization.

Fostering and facilitation of cooperation will be in line with the promotion of transparency and development of those that are not as advanced in technology and in the concept of no state operating in its sole interest but for the benefit of mankind.

Regulation is imperative as it allows there to be reference frames and checks and balances for activities in space. What is also very important is that regulation ties in with registration so that clear understanding of the actors is attained and there is full accounting of what is being done by whom and how within what specific guidelines.

5.3.2.2 Liability

Liability will be squarely on the organs of the international community, the states, which would be accountable to the outer space authority.

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[66] Government of South Africa, 1993, *Space Affairs Act of 1993*.

[67] Wolfrum, 1983, *The Principle of the Common Heritage of Mankind.*

[68] Wolfrum, 1983, *The Principle of the Common Heritage of Mankind.*

5.3.2.3 Transfer of Ownership

There will be no outright transfer of ownership of any celestial body or any determined part thereof based on the principle of non-appropriation. The framework will see entities being able to use authorized areas, which have been licenced to do so for a given period of time and for particularly defined usage or type of activities. There will however prevail a variant of the current terrestrial legislation which facilitates the transactions linked to resources and minerals.

5.3.2.4 Penalty for Contravening Policies and Principles Adopted Through Treaties and Agreements

Based on the serious nature of matters related to space utilization and the indeterminable and far-reaching damage that can result from perfunctory activities, penalties for contravention would have to be fitting of such and strong deterrents from include revocation of licence and expropriation (confiscation) of operation area for reassignment either to other deserving entity/ies or other determined usage types. It must be mentioned here that in the normal course of events, areas of exploration and usage would be subject to a system of best use and allocation.

5.3.3 US CSLCA of 2015 Model

The US CSLCA of 2015 has met with a fair amount of criticism both from within and outside the USA, the majority of this concerning the final section on asteroid mining. The Act is, however, more expansive than this final section. If the Act is to be analysed in terms of suitability for international application, it remains important to use a number of measurable factors.

What should an international viable framework include? As a departure point, the findings and recommendations of the Legal Subcommittee of COPUOS regarding the peaceful uses of outer space, as evidenced from collated national space regulatory frameworks. Categories considered for inclusion here are scope of application, authorization and licencing, safety, the continued supervision of non-governmental entities, registration, liability and insurance and transfer of ownership or control of space objects in orbit. These were later compiled into a UN General Assembly Resolution.[69]

As general categories of interest, and in essence as broad comparators, this report is also considering economic, safety, social, political, environmental and educational factors as a way to determine the efficacy of a particular framework (which of course, to some degree, overlap with the above).

[69] United Nations, 2013, *Recommendations on national legislation relevant to the peaceful exploration and use of outer space*.

However, the compartmental nature of the CSLCA must be considered. The majority of the Act does not concern space mining at all but concerns how to stimulate a competitive atmosphere within the US commercial space industry, remote sensing and redefining the office of space commerce. The international applicability and connection to space mining of these areas are slight.

If the CSLCA is to be used as an example of a commercial/industry-driven model as a viable international regulatory framework, only realistically does the final section (concerning space resource commercial exploration and utilization) provide insights.

This section briefly mentions safety (recovery of space resources should be free from harmful interference) and continued supervision (of non-governmental entities) but other than this is essentially a commercial (and to some degree economic) stipulation or mandate. In terms of the gamut of categories mentioned above, it remains therefore woefully lacking.

However, an overshadowing criticism of the Act is in terms of its lack of international focus and applicability as via the Act only US citizens and organizations can claim ownership rights to mined minerals. Critically, the Act does not provide for territorial dispute resolution between US entities and non-US ones (whether those be sanctioned via some other State's regulatory framework or not).

This can be viewed as a missed opportunity: in the case of the commercial exploration of the deep seabed, the US Congress recognized the rights of reciprocating State's laws. In this case, the USA appears to be almost haughtily assuming it will be the only state involved in space mining. The problem is however deeper than this: As a result of this siloed approach, the certainty of mining rights to an asteroid is compromised. Certainly no foreign state need accept or ratify US law should the Act have included this international applicability, but by potentially establishing a de facto cooperative standard, this would at least allow for a cooperative international proto-framework and would position the USA as a world leader in this regard.[70]

Looking at potential international regulatory frameworks from a commercial/industry-driven perspective (as evidenced here by the CSLCA) seems therefore to be fruitless. The strong national focus, with concern and emphasis going to intranational operators almost necessarily means that international concerns are overlooked. Most probably, this is therefore not the most viable departure point.

The current US CSLCA is reminiscent of the events around the Law of the Sea Treaty conception in 1982 by the United Nations. The treaty contains provisions on the regulation of deep-sea mining and the redistribution of wealth to underdeveloped countries, as well as sections regarding marine trade, pollution, research and dispute resolution.

Former US President Ronald Reagan objected to the treaty's principle of the "common Heritage of Mankind" that dictates which oceanic resources should be shared among all mankind and cannot be claimed by any one nation or people. Former President Reagan refused to sign the treaty in 1982 due to its innate conflict

[70] Simmons, T., 2016, *The unfortunate provincialism of the space resources act*, The Space Review. Available at: http://www.thespacereview.com/article/2910/1 [Accessed May 23, 2017].

with basic free-market principles (e.g. private property, free enterprise and competition).

The main theme is that some countries will not readily be willing to agree to rules set by the United Nations and the remaining countries need to either decide on what must be done to regain order or, as presented by the current situation, evaluate the options of backing status quo or going with the option of the "disruptor". If the choice made is the latter, then such countries must position themselves in such a way as to also help steer the conversation and in turn usher in new ways of thinking and doing.

5.3.4 Adoption of Terrestrial Mining Regulations Model

Mining and resource activities that fall within international scope of regulation are those minerals and resources falling within international special areas such as deep seabed mining.

Terrestrial mining activities are by and large regulated by domestic laws and have little to no international involvement as such. International involvement pertaining to terrestrial mining activities is confined to issues such as environmental issues, safety and labour requirements, human rights and international trade regulations.

To this end, it may be worth noting the procedures followed by the United Nations in 1991 when it involved private and public entities in convening a meeting with international mining experts in Berlin to address environmental issues relating to minerals. The Berlin Guidelines, which emerged, have subsequently been used as an industry guideline.[71]

5.3.5 Competing Interests in Regulatory Frameworks

Outer space, the deep seabed, and Antarctica share certain key components, namely, they are situated in international spaces; they are hostile environments for humans, are a potential source of valuable natural resources, and will require advanced technology to obtain and extract; and the cost of doing so will be excessive.[72]

[71] INTOSAI Working Group on Environmental Auditing, 2010, *INTOSAI WGEA Work Plan*. Available at: http://www.environmental-auditing.org/Home/WGEAActivities/WorkPlans/tabid/112/Default.aspx [Accessed May 23, 2017].

[72] Cook, K., 1999, *The Discovery of Lunar Water: An Opportunity to develop a workable Moon Treaty*, Georgetown Environmental Law Review, 11(3), 647–706.

Specific competing interests and concerns

Dichotomy	Interest/issue/concern
Industrialised states vs. developing States	Sharing of benefits derived from exploitation Transferring technology to developing States Creation of a competing enterprise Provision of property and licensing rights
Economic development vs. environmental protection	Preservation of the environment of the Moon and other celestial bodies Restrictions on exhaustive exploitation Use of nuclear and radioisotopic power sources and propulsion systems
International regulation vs. free market	Exclusivity of licences Minimum work requirements Essential protection of industrial property rights Controlling the economic effects of mineral exploitation on commodity markets
Public interest vs. commercial concerns	Satisfying the baseline resource needs of the least developed States Protection of developing States with terrestrial mineral resource production
Hard law vs. soft law	Need for binding legal principles Need for enforcement mechanisms Avoidance of unilateral regulation by States Need for flexible and adaptive rule-making

Fig. 5.10 Figure summarizing competing interests for asteroid mining (Lee 2012)

The international community has furthermore prioritized the conservation of these environments for future generations and attempts to apply the common heritage of mankind principles to them.[73]

The following five categories of competing interests arising for exploitation of near-Earth asteroids have been identified (Fig. 5.10)[74].

A common criticism of the common heritage of mankind doctrine is that it is restrictive of industrial development and consequently have practical and financial implications for states, hence the low level of states that have signed and ratified the Moon Agreement.[75]

For an international regulatory framework to be successful and carry sufficient legal recognition, it will require widespread international acceptance. As with the convention of the Law of the Sea, it will be necessary to find the appropriate compromise between public and private interests in order to gain international traction.[76]

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[73] Maslar, K., 1998, *The Concept of the Common Heritage of Mankind in International Law*, Brill, Leiden.

[74] Lee, R., 2012, *Law and Regulation of Commercial Mining of Minerals in Outer Space*, Springer Netherlands, The Hague.

[75] Listner, M., 2003, *The Ownership and Exploitation of Outer Space: A Look at Foundational Law and Future Legal Challenges to Current Claims*, Regent Journal of International Law.

[76] Lee, 2012, *Law and Regulation of Commercial Mining of Minerals in Outer Space*.

5.3.5.1 Industrialized States Versus Developing States

The Moon Agreement prohibits any form of private ownership or territorial sovereignty over celestial bodies.[77] In addition, the Outer Space Treaty further prohibits states from claiming sovereignty by means of use or occupation, *or any other means* over the Moon and other celestial bodies.[78]

As long private entities are not able to obtain property rights for the use or exploitation over celestial bodies, there will be no or limited incentive to obtain private investments.[79] However, the common heritage doctrine calls for an equitable sharing of benefits derived from the exploitation of such common heritage sites with the rest of mankind.[80]

The international community attempted to navigate this dichotomy by the implementation of the International Seabed Authority which adopted a royalty/profit-sharing system set out in the Agreement Relating to the Implementation of Part XI of the UN Convention on the Law of the Sea of 10 December 1982.[81]

Insofar as transfer of technology is concerned, provision for mandatory transfer of technology is made in the Convention of the Law of the Sea[82] and the 1994 Agreement.[83] It is suggested however that technological capabilities required for mining of celestial bodies are not only sensitive but extensive and include reference to rocketry capabilities, robotic technologies, power generation and propulsion systems, computerized targeting technologies, mineral processing capabilities and so forth.[84] These activities and technologies overlap with military technologies, and states would not be disinclined to share same, if not in any event restricted from doing so in terms of the Wassenaar Arrangement.[85]

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[77] United Nations, 1979, *Agreement Governing the Activities of States on the Moon and Other Celestial Bodies*, United Nations, New York.

[78] United Nations, 1979, *Agreement Governing the Activities of States on the Moon and Other Celestial Bodies*, Article 11.

[79] Davis, S., 2001, *Unifying the Final Frontier: Space Industry Financing Reform*, Commercial Law Journal, 106(4), 455ff.

[80] United Nations, 1979, *Agreement Governing the Activities of States on the Moon and Other Celestial Bodies*, Article 11(7); Harminderpal, S.R., 1994, *The "Common Heritage of Mankind" & the Final Frontier: A Revaluation of Values Constituting the International Legal Regime for Outer Space Activities*, Rutgers Law Journal, 26, 225ff.; and Gilpin, R., 2001, *Global Political Economy: Understanding the International Economic Order*, Princeton University Press, Princeton.

[81] United Nations, 1994, *Agreement relating to the implementation of Part XI of the United Nations Convention on the Law of the Sea of 10 December 1982*, United Nations, New York.

[82] United Nations, 1994, *Agreement relating to the implementation of Part XI of the United Nations Convention on the Law of the Sea of 10 December 1982*, Article 144.

[83] Opened for signature on 28 July 1994, 1836U.N.T.S. 3; 33 I.L.M. 1309 (entered into force on 28 July 1996), Annex, Section 5.

[84] Lee, 2012, *Law and Regulation of Commercial Mining of Minerals in Outer Space*, 280 f.

[85] Wassenaar Arrangement Secretariat, 2009, *The Wassenaar Arrangement On Export Controls for Conventional Arms and Dual-Use Goods and Technologies*. Available at: http://www.wassenaar.org/ [Accessed May 22, 2017].

5.3.5.2 Economic Development Versus Environmental Safeguards

The Outer Space Treaty requires that states "conduct exploration … so as to avoid their harmful contamination and also adverse changes in the environment of the Earth resulting from the introduction of extraterrestrial matter and, where necessary, shall adopt appropriate measures for this purpose".[86] The treaty however fails to define the term "harmful contamination".[87]

The Moon Agreement attempts to further oblige states to "prevent the disruption of the existing balance of its environment, whether by introducing adverse changes in that environment, by its harmful contamination through the introduction of extra-environmental matter or otherwise" (Moon Agreement).[88]

The potential of space mining becoming a reality necessitates the need for further urgent clarity not only to avoid economic abuse in the absence of clear prohibitions to environmental harm to outer space and the Earth environment but also to provide private commercial entities and the states overseeing their activities with sufficient information to navigate their legal responsibilities.

Given the difficulties surrounding propulsion methods and the need for a more efficient and effective method of such propulsion systems, there is great benefit for involving private commercial entities in developing, testing and manufacturing methods, which would include the use of nuclear and radioisotope fuel cells.[89]

Care must be taken to introduce regulatory measures consistent with existing international laws to avoid introducing any radioactive materials into the Earth's atmosphere, or from making contact with the Earth's surface when spacecraft engaged in mining activities re-enter the Earth's atmosphere, and responsible waste disposal methods.

5.3.5.3 Regulation Versus Free Market

The unilateral regulatory approach adopted by the USA in opposition to the Convention of the Law of the Sea highlights the need for a single international regulatory authority to regulate celestial mining activities.[90] It has been suggested that such international regulatory authority ought to administer exclusivity in licencing to avoid disputes arising between states having granted exclusivity rights to private

[86] United Nations, 1967, *Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies.*

[87] United Nations, 1967, *Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies.*

[88] United Nations, 1979, *Agreement Governing the Activities of States on the Moon and Other Celestial Bodies*, Article 7(1).

[89] Lee, 2012, *Law and Regulation of Commercial Mining of Minerals in Outer Space*.

[90] Oliver, C.D., 1981, *Interim Deep Seabed Mining Legislation: An International Environmental Perspective*, Journal of Legislation, 8(1), 73–103.

entities over the same areas and/or activities and the validity of licences. Similarly, such authority will avoid the duplication of the Tonga saga.[91]

The potential influx of scare or unique and valuable commodities may have severe negative consequences on the global commodity markets and will require intervention to avoid economic destabilization, especially given that various developing states rely heavily on mineral trade.[92]

5.3.5.4 Public Interest Versus Commercial Concerns

Similar to the baseline supply obligations referred to in the International Telecommunication Satellite Organisation (INTELSAT and International Maritime Satellite Organisation (INMARSAT) mineral resources) will be subject to demand by developing nations in order to survive and meet their basic needs.[93,94]

Economic interest of private or industrialized states should however not be overburdened by demands to assist least developed countries with appropriate funding and minimum resource requirements and the appropriate regulatory authority need to provide adequate protection on both sides.[95]

5.3.5.5 Hard Law Versus Soft Law

UN law-making activities in the space arena appear to have shifted from drafting and adopting multilateral treaties to General Assembly declarations.[96] The binding nature of General Assembly resolutions is still controversial.[97]

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[91] Andrews, E., 1990, *Tiny Tonga Seeks Satellite Empire in Space*, The New York Times.

[92] Friedman, M., 1954, *The Reduction of Fluctuations in the Incomes of Primary Producers: A Critical Comment*, Economics Journal, 64, 698–703; Bevan, D., Collier, P., & Gunning, J.W., 1993, *Trade shocks in developing countries: Consequences and policy responses,* European Economic Review, 37(2–3), 557–65; Davis, J., 1983, *The economic effects of windfall gains in export earnings 1975–1978,* World Development, 11(2), 119–39; and Lee, 2012, *Law and Regulation of Commercial Mining of Minerals in Outer Space*, 289.

[93] Panzar, A., 2000, *A methodology for measuring the costs of universal service obligations*, Information Economics and Policy, 12(3), 211–20.

[94] Katkin, K., 2005, *Communication Breakdown? The Future of Global Connectivity After the Privatisation of INTELSAT*, Vanderbilt Journal of Transnational Law, 38(5), 1323–1402; and United Nations Office of the High Representative for the Least Developed Countries, Landlocked Developing Countries and Small Island Developing States, 2016, *Criteria for Identification and Graduation of LDCs*. Available at: http://unohrlls.org/about-ldcs/criteria-for-ldcs/ [Accessed May 22, 2017].

[95] Lee, 2012, *Law and Regulation of Commercial Mining of Minerals in Outer Space*.

[96] Lee, 2012, *Law and Regulation of Commercial Mining of Minerals in Outer Space*.

[97] Lee, 2012, *Law and Regulation of Commercial Mining of Minerals in Outer Space*.

The international community has thus far purposely avoided the creation of binding dispute settlement and enforcement mechanisms,[98] specifically with reference to the claims commission referred to in the Convention on the International Liability for Damages Caused by Space Objects.[99]

In order to adequately provide an adequate regulatory framework for mining activities in outer space, enforcement mechanisms in all areas relevant to the exploration, sourcing, extracting and utilization of minerals must form part of such regulatory framework[100], and it will be necessary for member states to adopt such binding and mandatory enforcement mechanisms.

As seen with previous attempts to regulate international "common heritage" resources, restrictive laws fail to gain sufficient international traction from industrialized states and private entities, whilst soft law fails to adequately provide adequate protection for developing nations. In addition, private commercial enterprises will require sufficient clarity that its activities will not in the long run become subject to retrospective legal restrictions, before investing in such activities.

5.3.5.6 Practical Implications for a New Regulatory Framework

In addition to imposing a regulatory framework, various practical implementation issues will have to be resolved, including the structure, composition, functions and powers of an international authority to deal with outer space activities, including commercial mining.

RJ Lee[101] suggests one optional structure for an international space development authority, illustrated as follows:

Membership to such a proposed international regulatory authority could be addressed through different approaches, including membership limited to spacefaring nations, membership limited to states that have made a financial investment to the commercial activities of such authority, membership open to all member states of the UN or membership open to all states regardless of membership to the UN.[102]

Limited access models to international regulatory authorities are not unique and have been applied before, for example, the 1959 Antarctic Treaty limited participation to states that have demonstrated their interest in Antarctica (Fig. 5.11).[103]

It has been suggested that limited membership may undermine the legal effectiveness of the objective of an international regulatory framework of outer space

[98] Lee, 2012, *Law and Regulation of Commercial Mining of Minerals in Outer Space*.

[99] United Nations, 1972, *Convention on International Liability for Damage Caused by Space Objects,* United Nations, New York, Article XIX.

[100] Froehlich, 2017, *Utilization – Consumption – Appropriation: Asteroid mining is in the pipeline*.

[101] Lee, 2012, *Law and Regulation of Commercial Mining of Minerals in Outer Space*.

[102] Lee, 2012, *Law and Regulation of Commercial Mining of Minerals in Outer Space*.

[103] Antarctic Treaty, opened for signature on 1 December 1959, 402 U.N.T.S. 71; 12 U.S.T. 794; 19 I.L.M. 860 (entered into force on 23 June 1961), Article IX.

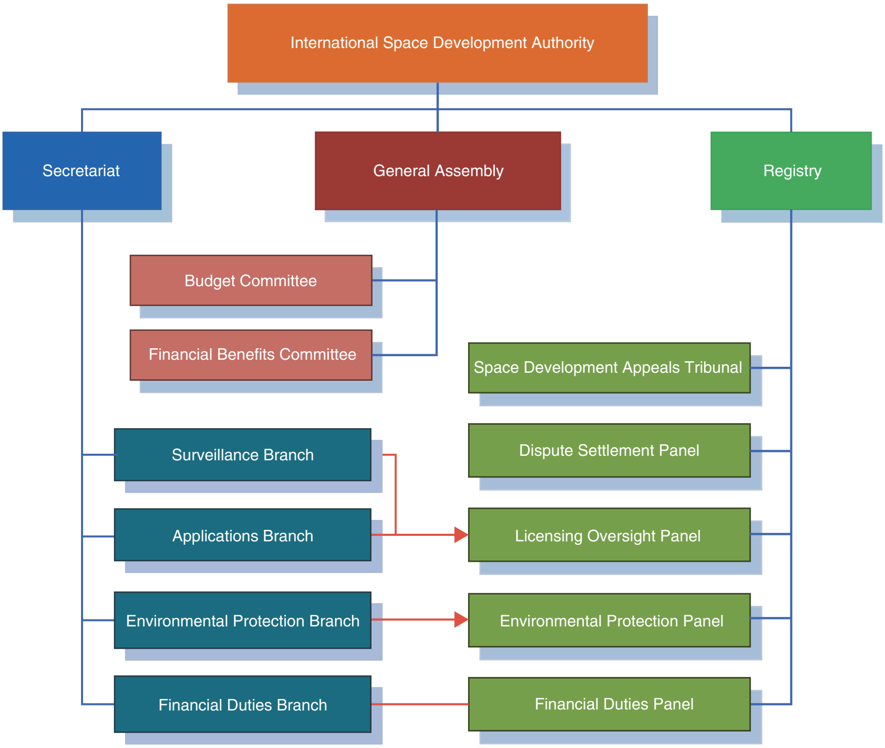

Fig. 5.11 Figure outlining the proposed international space development authority (Lee 2012)

activities and would fail to provide adequate legal certainty in respect of non-member states and their subjects.[104]

In addition, the issue of granting membership to non-state entities will also require attention along with the method of granting such membership. Various international organizations have non-state members and generally two methods of acceptance of membership prevail, namely, automatic admission on accession to the relevant treaty or convention, versus two-thirds majority vote by the existing members.[105]

Other international organizations such as the International Atomic Energy Agency, International Fund for Agricultural Development, World Bank and World Trade Organisation have specific rules pertaining to non-state membership.[106]

[104] Lee, 2012, *Law and Regulation of Commercial Mining of Minerals in Outer Space*.

[105] Lee, 2012, *Law and Regulation of Commercial Mining of Minerals in Outer Space*.

[106] Membership to the International Fund for Agricultural Development requires approval by the Governing Council, in which voting rights are based on membership and financial contribution: Agreement Establishing the International Fund for Agricultural Development, opened for signature on 20 December 1976, 28 U.S.T. 8435; 15 I.L.M. 922 (entered into force on 30 November 1977), Articles 3 and 6. Membership subject to approval by a simple majority of the General

5.3.5.7 Administrative and Dispute Settlement Mechanisms

Disputes will be inevitable, not only between states and non-states but between applicants and the international regulatory authority, and the need will therefore arise for judicial accountability.[107]

It has been suggested that various panels be established to assist with the determination of different disputes, such as a licencing oversight panel, environmental protection panel, financial duties panel, dispute settlement panel and space development appeals tribunal.[108]

The cost of space activities is exorbitant, and the activities require sustained long-term investment. With the rise of private commercial space activities and cooperative efforts between state and private international entities, space activities will hopefully advance more rapidly.

However, the absence of an appropriate legal framework presents in itself a barrier to further exploration and actualization of extraterrestrial activities. It is undisputed that the need exists for a regulatory framework to deal with outer space activities of states and private entities alike. In doing so, it will become necessary to grapple with the legal complications of the existing outer space treaties and especially the impasse presented by the Moon Agreement.[109]

Historical attempts at dealing with mineral and resource extraction in international special areas have failed in certain respects and highlighted the need to impose greater regulatory clarity and establish binding authorities to deal with the challenges and conflicting interests of the various stakeholders.

Given the time needed to consider an appropriate regulatory forum and authorities to attend to space activities, it is necessary to start the process now in order that the framework may be established by the time commercial activities relating to extraterrestrial mining are undertaken.

Conference upon recommendation by the Board of Governors: Statute of the International Atomic Energy Agency, opened for signature on 26 October 1956, 276 U.N.T.S. 3; 8 U.S.T. 1093 (entered into force on 29 July 1957), Articles IV and V; Membership is open to the Member States of the International Monetary Fund: Articles of Agreement of the International Bank for Reconstruction and Development, Article II; Membership is to be on specific terms approved by a two-thirds majority of the Ministerial Conference: Agreement Establishing the World Trade Organisation, opened for signature on 15 April 1994, 1867 U.N.T.S. 154; 33 I.L.M. 1144 (entered into force on 1 January 1995), Article XII.

[107] Froehlich, 2017, *Utilization – Consumption – Appropriation: Asteroid mining is in the pipeline*; Lee, 2012, *Law and Regulation of Commercial Mining of Minerals in Outer Space*.

[108] Froehlich, 2017, *Utilization – Consumption – Appropriation: Asteroid mining is in the pipeline*; Lee, 2012, *Law and Regulation of Commercial Mining of Minerals in Outer Space*.

[109] Froehlich, 2017, *Utilization – Consumption – Appropriation: Asteroid mining is in the pipeline*.

5.3.6 Combined Regulatory Authorities Model

When considering potential regulatory options as they relate to space activities, most countries with existing frameworks follow one of two routes, either by regulating space activities through a unified national space authority or by regulating through a combination of various authorities.[110] As such, countries largely pursue one of these regulatory paths based on the state of their space industries and their specific needs, particularly with reference to the types of space activities that are being pursued and the extent to which the private sector is involved.[111]

Countries without extensive or well-developed space industries may choose to pursue the model that features regulation by various authorities as this option does not require significant investment or new setup of administrative bodies. This option features the expansion or inclusion of space activities in the already existing mandates of national bodies or authorities that could reasonably regulate the relevant space activities.

For example, if a country such as South Africa that has a relatively limited space industry seen through its launch of only three satellites,[112] it may not prove efficient to invest state resources into a completely new and unified regulatory infrastructure for all space activities. Indeed, the South African Council for Space Affairs (SACSA) was established in 1993 to authorize and licence satellite launch and operations[113]; however, other space-related authorities exist in South Africa such as the Department of Science and Technology named in the Astronomy Geographic Advantage Act,[114] as opposed to the Department of Trade and Industry overseeing SACSA and the South African Civil Aviation Authority.[115]

Therefore, if a country seeks to establish regulations on extraction and utilization of space resources yet the space industry in that country remains at a comparatively low level of development and if the extent of the private sector's involvement in the industry remains low, then it may prove beneficial for a country to adopt a regulatory regime that remains responsible and enforceable among various and already existing regulatory authorities. In particular, regulation of space mining may be implemented and enforced by a country's relevant natural resource management or extractive industries authority if it does not pursue a unified national regulatory authority centralizing the regulation of space activities.

110 United Nations Committee on the Peaceful Uses of Outer Space, 2014, *Schematic overview of national regulatory frameworks for space activities*, United Nations, Vienna.

111 United Nations Committee on the Peaceful Uses of Outer Space, 2014, *Schematic overview of national regulatory frameworks for space activities*.

112 South African Council for Space Affairs, 2013, *National Registry of Objects Launched into Outer Space*. Available at: http://www.sacsa.gov.za/registry/index.php [Accessed May 26, 2017].

113 Government of South Africa, 1993, *Space Affairs Act of 1993*.

114 Government of South Africa, 2008, *South African National Space Agency Act*.

115 South African Civil Aviation Authority, 2016, *SACAA Mandate*. Available at: http://www.caa.co.za/Pages/About%20Us/SACAA-Mandate.aspx [Accessed May 26, 2017].

The combined regulatory approach offers the country benefits in that the government would not require significant investment in establish a new authority, yet the approach may also feature drawbacks to the government and its regulations as the authority which would be mandated with regulation of space mining may not be in a position technically to conduct effective oversight and regulation. Space mining brings a host of unique challenges to regulation as compared to its terrestrial counterpart as described elsewhere in this report; therefore, investment in the authority may be required to develop the technical ability of its regulators to effectively perform their oversight. Additionally, this may create redundancies among the overall government regulatory regime as those already present in space regulatory agencies may have the technical skills to offer oversight, yet these would not necessarily be transferable to the newly tasked regulator for space mining given competing priorities for the respective agencies. It would necessarily remain incumbent on any government pursuing this combined regulatory approach to space mining to ensure resources are evenly distributed across the whole of government and to limit redundancies where possible when tasking an existing agency with regulation of space mining activities.

Chapter 6
Recommendations on South Africa's Position

6.1 South Africa's Position in Particular with Regard to the Moon Agreement, Which South Africa Has Not Signed

It will take time to put into place international regulatory framework to govern extraterrestrial mining and resource utilization activities.

The framework which will govern extraterrestrial mining and resource utilization will likely not be an extension of the Moon Treaty itself since same has received very limited support in the international community. In the circumstances, it is likely that a new set of guiding principles will emerge which will first be nonbinding guidelines and standards.

Over time, these principles may through repeated adoption and recommendation by the general assembly become entrenched in international soft law and may further become the "international industry standard". It has been suggested that the framework which will govern extraterrestrial mining and resource utilization will evolve in a similar manner to international environmental law, instead of it being governed by a uniformly accepted multilateral treaty like the Moon Treaty.[1]

The reason for this is that states are cautious to accede to international treaties which impose burdensome obligations on them, especially when future development is still largely undefined and may thus have unintended negative consequences. This is especially true for extraterrestrial mining and potential restrictions to private commercial enterprise.

Considering South African context, realistically South Africa does not have the infrastructure and scope to participate in extraterrestrial mining activities per se; however, as a mining country, that does not mean that South Africa will not

[1] Lee, 2012, *Law and Regulation of Commercial Mining of Minerals in Outer Space*.

A. Froehlich (ed.), *Space Resource Utilization: A View from an Emerging Space Faring Nation*, Studies in Space Policy 12,
https://doi.org/10.1007/978-3-319-66969-4_6

participate in the "on-ground" activities indirectly contributing to space mining, e.g. research and development.

In addition, as one of the BRICS nations, South Africa is in a favourable position to gain advantage by association. It is therefore important that the regulatory framework of choice is in line with these partner states to facilitate mutual cooperation, obviously still bearing the country's international obligations in mind.

Nevertheless, South Africa's involvement in extraterrestrial mining will be minimal, if at all, simply because the economy, research capabilities and resources as a developing country are small compared to what is required of a country that is actively involved in space exploration and furthermore due to SA's competing national interests.

SA will have far better "return" for investment if it focuses its investment on involvement in space technology and application on the ground. SA will furthermore need to focus on international cooperation and collaboration such as IBSA and regional cooperation within Africa such as involvement in ARMC, ALC, RASCOM and the like.

Notwithstanding our minimal involvement in actual extraterrestrial space activities, South Africa must take every opportunity, as a developing country, to remain involved in the discussion leading up to and ultimately the formation of an international regulatory framework to govern extraterrestrial space activities.

An adequate regulatory framework for mining activities in outer space, enforcement mechanisms in all areas relevant to the exploration, sourcing, extracting and utilization of minerals must form part of such regulatory framework, and it will be necessary for member states to adopt such binding and mandatory enforcement mechanisms.

South Africa's recommendations ought to contain the following elements:

1. The principles established in the outer space treaties, such as the preservation of the common heritage sites.
2. The principles set out in the Principles Relevant to the Use of Nuclear Power Sources in Outer Space, adopted on 14 December 1992 (resolution 47/68), and Declaration on International Cooperation in the Exploration and Use of Outer Space for the Benefit and in the Interest of All States, Taking into Particular Account the Needs of Developing Countries, adopted on 13 December 1996 (resolution 51/122, annex), should be incorporated into such international framework to ensure that the involved states do not overstep the line.
3. Whilst the Moon Treaty is generally not ratified, the principles relating to common heritage and "benefit of developing countries" cannot be dismissed as these principles are sufficiently entrenched in international law to be considered – even if not binding.
4. We need to recommend that the UN establish the necessary regulatory bodies to ensure that international principles pertaining to human rights, safety, environmental law (including space debris mitigation guidelines) and international trade are not abused by states or private commercial enterprise, although it is necessary

to concede that such provisions cannot be so restrictive on space activities undertaken by private entities that it has the effect of barring entry.

As described above, multiple issues relate to the concept of resource extraction and utilization in space. These range from those inherited from decades-old international space treaties and nonbinding resolutions and principles developed through the UN system to those associated with the rapid pace of space development and the evolving nature of the space industry with the introduction of private sector stakeholders. Given this, it has remained important to assess the current international and national frameworks that pertain to space resource extraction and utilization, understand the views of both established and emerging space nations and consider the various regulatory options and their potential areas for responsibility available for countries and the international community to adopt on the topic. This was further done to develop a position for South Africa on the subject and determine whether South Africa would benefit from the ratification and domestication of international laws such as the Moon Agreement.

As South Africa has ratified four of the five major outer space treaties (the Moon Agreement being the exception), it is incumbent upon South Africa's policymakers to ensure compliance with the spirit and principles of these treaties in any position taken towards space resource extraction and utilization as previously described in the report. On the question of whether South Africa should adopt and ratify the Moon Agreement and use this as a move towards promoting a certain principled approach to space resource extraction, this is answered in the above by stating South Africa's commitment towards regulatory alignment with its BRICS partners. In its approach to the subject and as also previously stated, whilst commitment towards common heritage principles is critical to South Africa's continental participation, for South Africa to participate in the global space arena, broader socio-economic considerations need to be embraced.

Beyond these recommendations for South Africa to move forward, it remains critical for this report to end by reflecting on the future and the implications of space resource extraction and utilization. In particular, this question and its answers prove incredibly important for South Africa given its significant economic reliance on the terrestrial resource extraction industry. Any such development of a space-based resource extraction industry would have a significant impact on economies such as South Africa's and carries great risk if not constructively managed for tho2se that are even less diversified and more singularly reliant upon raw materials and resource extraction as seen elsewhere in developing countries and in particular those in sub-Saharan Africa.

If improperly managed, the space resource extraction industry could have devastating ramifications for terrestrial-based industries as global resource markets would potentially experience significant supply increases thus leading to greatly reduced market prices and collapsing already fragile or risk-prone economies. However, it is unlikely such a collapse in market prices would occur overnight as space-based industries would retain incentives to keeping prices as high as possible in order to recoup research and development and capital investment expenditures. Therefore, South Africa's position and voice in the international community would prove beneficial towards the stewardship of space resources and regulation of the industry given the country's substantial interests in the already established terrestrial resource extraction industry.

The above report serves this purpose of supporting South Africa to take an informed position and therefore seeks to ensure the sustainability and growth of the country's economy and secure its future development as a major stakeholder in space activities.

6.2 Policy Development Pathway

Policy is defined by the Oxford Dictionary as "a course or principle of action adopted or proposed by an organisation or individual".

The South African Space Council, a creature of statute, has been tasked with implementation of the Space Affairs Act 84 of 1993 (Space Affairs Act). Section 5(1) of the Space Affairs Act provides that "The objects of the Council are to implement, in the most efficient and economical manner possible, the space policy of the Republic formulated in terms of section 2".[2]

Section 2(1) of the Space Affairs Act provides that "Subject to subsection (2), the Minister may, by notice in the Gazette, determine the general policy to be followed with a view to (a) meeting all the international commitments and responsibilities of the Republic in respect of the peaceful utilization of outer space, in order to be recognized as a responsible and trustworthy user of outer space; and (b) controlling and restricting the development, transfer, acquisition and disposal of dual-purpose technologies, in terms of international conventions, treaties and agreements entered into or ratified by the Government of the Republic".[3] Section (2)(2) provides that "The policy contemplated in subsection (1) shall be determined by the Minister after consultation with the Council".[4]

Article I of the Moon Agreement sets the basis for any space exploration and mining activities in that it provides that "The exploration and use of outer space, including the Moon and other celestial bodies, shall be carried out for the benefit and in the interests of all countries, irrespective of their degree of economic or scientific development, and shall be the province of all mankind".[5]

The Space Affairs Act defines objectives for developing a space policy for South African space activities. Currently, the Space Affairs Act's objectives are to comply with international commitments and responsibilities including outer space mining.

[2] Government of South Africa, 1993, *Space Affairs Act of 1993*.

[3] Government of South Africa, 1993, *Space Affairs Act of 1993*.

[4] Government of South Africa, 1993, *Space Affairs Act of 1993*.

[5] United Nations, 1967, *Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies*.

Whilst South Africa has no immediate intention of mining celestial bodies in outer space, it binds itself that it will honour international agreements and treaties.

Policy development commences with setting out what one wants to achieve. In this case, South Africa wants to participate in the regulation and mining of celestial bodies in outer space.

Chelsey Bonehill in her paper suggests that policy development framework has a number of stages including the business case (objectives and strategic intent of the policy), the link between strategy and policy (alignment), governance arrangements for policy "sign off" and launching the policy (adoption of policy), policy implementation (enforcement including monitoring and reporting) and policy review.[6]

South Africa should first identify and recognize both its ability and capability to play a meaningful the role in outer space exploration. Section 5(1) of the Space Affairs Act requires the Space Council to develop an effective and efficient space policy.

South Africa must recognize that it has minimal space exploration infrastructure. Further, that even if it had adequate space exploration infrastructure it would face serious competition. As such, South Africa would not be able to realize a good return on investment in exploration infrastructure such as rocket-launching facilities.

Further, South Africa's economy, research capabilities and resources as a developing country are small compare to what is required of a country that is actively involved in space exploration. National internal competing interests for resources in South Africa favour the use of available resources to more pressing national issues. Thus, if South Africa were to look at outer space mining then a different approach is required. Regional cooperation in outer space mining is a key success factor.

The main objective of the proposed policy is to both enable South Africa to participate in outer space mining activities and ensure that South Africa continues to comply with its international commitments and responsibilities.

With the status quo of South Africa in mind, the best policy pathway for the time being would that of leveraging regional and international cooperation on space exploration and outer space mining in particular. South Africa currently belongs to the Southern African Development Community (SADC) and Group of Brazil, Russia, India, China and South Africa (BRICS) institutions.

The Council for Space Affairs should engage both SADC and BRICS to bolster its capability for space exploration and outer space mining of celestial bodies. South Africa should set up bodies through which it can create economies of scale that would result in meaningful participation in outer space mining.

Further, South Africa should align its interests in space explorations with those of member countries of both the regional and international grouping. This requires alignment of space exploration policies of SADC and BRICS member states. South Africa should facilitate a process in which representatives of both SADC and BRICS member states enter into an agreement on outer space cooperation in both exploration and mining of celestial bodies.

[6] Bonehill, C., 2007, *Policy Development Framework*, CAFCASS, London.

Section 3 of the Space Affairs Act provides that "Each Minister upon whom, or government institution upon which, any power has been conferred or to whom or which any duty has been assigned in connection with space affairs by or under any law, shall exercise such power and perform such duty in accordance with the policy determined in terms of section 2".[7]

The Space Council has a duty to ensure that national space policy is implemented. This includes implementation of any agreements South Africa has concluded both regionally and internationally.

National representatives of the SADC and BRICS member states should agree on creating a space policy implementation body. This body should also ensure that member states ratify the cooperation agreement on outer space mining. Further, this body would ensure that there is an effective governance regime to ensure effective implementation of outer space exploration and mining policy adopted by the parties to the agreement.

It is proposed that a separate body should be created by SADC and BRICS member states to monitor and evaluate implementation of outer space policy of the two groups. A policy is a living way of doing things.

Consequently, it requires adjustment in line with the changes of both the needs of a country and context in which the policy is implemented. Mining of celestial bodies is one such factor that influences changes in policy and later legislation.

The parties to regional and international cooperation through SADC and BRICS should agree on criteria that will trigger a review of outer space exploration and celestial bodies mining policy. This criteria may either be time or event based.

The only economically viable way for South Africa to participate meaningfully in outer space exploration and mining activities would be to cooperate regionally and internationally. SADC and BRICS provide a foundation for South Africa to become a meaningful player in space exploration and mining of celestial bodies.

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[7] Government of South Africa, 1993, Space Affairs Act of 1993.

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The *SpaceLab of the University of Cape Town* offers a master's program in Space Studies which starts with the Space and Society course. This course is copresented by Prof Peter Martinez from the University of Cape Town and Dr Annette Froehlich from the European Space Policy Institute/German Aerospace Center and Honorary Adjunct Senior Lecturer of the University of Cape Town. This module covers the key societal aspects of space activities, such as space policy, space law, space economics, commercial space activities, space program management, international cooperation, and space security.

Appendices

Appendix A: Established Countries' Ratification

Table A.1 Summary of established countries who have signed and ratified the various UN treaties

	Outer Space Treaty (OST 1967)	Moon Agreement (Moon 1984)	Rescue Agreement (OST 1968)	Liability Convention (LIAB 1972)	Registration Convention (REG 1975)
USA	Ratification	Not signed/ not ratified	Ratification	Ratification	Ratification
Russia	Ratification	Not signed/ not ratified	Ratification	Ratification	Ratification
India	Ratification	Signed	Ratification	Ratification	Accession
Republic of Korea	Ratification	Not signed/ not ratified	Ratification	Ratification	Accession
Japan	Ratification	Not signed/ not ratified	Accession	Ratified	Accession
Austria	Ratification	Ratification	Ratification	Ratification	Ratification
Denmark	Ratification		Ratification	Ratification	Ratification
Belgium	Ratification	Accession	Ratification	Ratification	Ratification
Finland	Ratification		Ratification	Ratification	
France	Ratification	Signed	Ratification	Ratification	Ratification
Germany	Ratification		Ratification	Ratification	Ratification
Greece	Ratification		Ratification	Ratification	Ratification
Iceland	Ratification		Ratification	Signed	
Ireland	Ratification		Ratification	Ratification	
Italy	Ratification		Ratification	Ratification	Ratification
Luxembourg	Ratification		Signed	Ratification	
Netherlands	Ratification	Ratification	Ratification	Ratification	Ratification
Norway	Ratification		Ratification	Ratification	Ratification

(continued)

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Table A.1 (continued)

	Outer Space Treaty (OST 1967)	Moon Agreement (Moon 1984)	Rescue Agreement (OST 1968)	Liability Convention (LIAB 1972)	Registration Convention (REG 1975)
Portugal	Accession		Ratification		
Spain	Accession		Ratification	Ratification	Ratification
Sweden	Ratification		Ratification	Ratification	Ratification
Switzerland	Ratification		Ratification	Ratification	Ratification

Appendix B: Eros

Presuming *Planetary Resources* builds a fleet of prospecting space telescopes, locates mineral-bearing space rocks, gets to them, and successfully mines them, and then what? Can a corporation lay claim to these protoplanetary leftovers, and can they really sell them? Or are they part of our common celestial heritage, priceless pieces of early creation that should be protected?

At the heart of the space asset ownership debate is the 1967 Outer Space Treaty, a Cold War relic that prohibits establishment of colonies or sovereign rights on the moon or other celestial bodies. Private companies are not necessarily prohibited from establishing settlements, but the treaty also holds that states oversee and regulate these putative companies and their activities and assume liability for any bad scenarios.

Regarding property rights, the case of Gregory W. Nemitz and the *Eros Project* offers some perspective. Nemitz claimed ownership of asteroid 433 Eros, one of the largest asteroids in a near-Earth orbit and one with abundant supplies of aluminum, iron, potassium, and magnesium, among other metals. The Eros Project seeks to establish a mining colony on the asteroid and develop these materials, according to its website. In 2000–2001, NASA's NEAR Shoemaker spacecraft orbited the asteroid and eventually landed on its surface. Nemitz sued NASA for parking fees. His case was dismissed, but NASA's arguments and reference to the Outer Space Treaty note that space and space objects are "not subject to national appropriation" (Orbdev Files Federal Suit Over Eros Claim 2016).

As of now, the USA is the only entity to bring space objects home that would be of any value. The Japanese last year retrieved some space dust from the *Hayabusa asteroid lander*, but its value was purely scientific, not commercial. Bringing home loads of platinum, water, or any other resource would be a different story, and there's no jurisprudence on that yet.

As long as Planetary Resources doesn't try to claim ownership of the asteroids it mines, this argument may not arise. But it's not a far leap to imagine what the company will do if competitors try to jump its mining claims.

Appendix C: GDP Ranking

Table A.2 Based on Campbell 2014, European Space Policy Institute 2016, and Statistics Time 2016

Country	GDP in 2015	Annual public space budgets	Percentage spend
USA	$17968 B	$44,57 B	0.2481%
Russia	$1236 B	$2,99 B	0.2419%
France	$2423 B	$2,03 B	0.0837%
Japan	$4116 B	$2,66 B	0.0646%
India	$2183 B	$ 912 M	0.0418%
Germany	$3371 B	$1,31 B	0.0389%
China	$11385 B	$4,21 B	0.0370%
Italy	$1819 B	$ 653 M	0.0359%
Canada	$1573 B	$ 388 M	0.0247%
South Africa	$ 317.3 B	$ 9,12 M	0.0028%

References

J. Amos, Luxembourg to support space mining (BBC, 2016a). Available at: http://www.bbc.com/news/science-environment-35482427. Accessed 18 May 2017

J. Amos, Mars TGO probe despatched on methane investigation (BBC, 2016b). Available at: http://www.bbc.com/news/science-environment-35799792. Accessed 18 May 2017

E. Andrews, Tiny Tonga seeks satellite empire in space (The New York Times, 1990)

S. Asher, P. Novosad, *Dirty Politics: Natural Resources Wealth and Politics in India* (Oxford University, Oxford, 2014)

J. Avins, China's "Jade Rabbit" rover found a new kind of moon rock (Quartz, 2016). Available at: http://qz.com/581824/chinas-jade-rabbit-rover-found-a-new-kind-of-moon-rock/. Accessed 19 May 2017

L. Barnard, UAE to finalise space laws soon (The National, 2016). Available at: http://www.thenational.ae/business/aviation/uae-to-finalise-space-laws-soon. Accessed 18 May 2017

K. Barnato, Lift-off: Luxembourg's asteroid mining plan (CNBC, 2016). Available at: http://www.cnbc.com/2016/02/03/luxembourgs-asteroid-mining-plan.html. Accessed 18 May 2017

BBC News, Falling oil prices: How are countries being affected (2016). Available at: http://www.bbc.com/news/world-35345874. Accessed 18 May 2017

D. Bevan, P. Collier, J.W. Gunning, *Trade shocks in developing countries: consequences and policy responses*. Eur. Econ. Rev. 37(2-3), 557–565 (1993)

B.R. Blair, *The Role of Near-Earth Asteroids in Long-Term Platinum Supply* (Colorado School of Mines, Golden, 2000)

P. Boffetta et al., *Mortality from cardiovascular diseases and exposure to inorganic mercury*. Occup. Environ. Med. **58**(7), 461–466 (2001)

C. Bonehill, *Policy Development Framework* (CAFCASS, London, 2007)

A. Brownlee, The economics of mining in space (n.d.). Available at: http://www.investopedia.com/articles/investing/121415/economics-mining-space.asp. Accessed 18 May 2017

G. Calvo, G. Mudd, A. Valero, A. Valero, *Decreasing ore grades in global metallic mining: a theoretical issue or a global reality?* Resources **5**(4), 36–49 (2016)

K. Campbell, DST prioritises human capital, R&D infrastructure, innovation and new knowledge (Engineering News, 2014). Available at: http://www.engineeringnews.co.za/print-version/dst-prioritises-human-capital-rd-infrastructure-innovation-and-new-knowledge-2014-07-22. Accessed 26 May 2017

C.Q. Christol, *Space Law: Past, Present and Future* (Kluwer, Deventer, 1991)

CNBC, Asteroid mining will be "trillion-dollar business" (2016). Available at: http://video.cnbc.com/gallery/?video=3000500435. Accessed 18 May 2017

A. Froehlich (ed.), *Space Resource Utilization: A View from an Emerging Space Faring Nation*, Studies in Space Policy 12,
https://doi.org/10.1007/978-3-319-66969-4

S. Coffey, Establishing a legal framework for property rights to natural resources in outer space. Case Western Reserve J. Int. Law **41**(1), 119–147 (2009)

M.M. Cohen, Robotic Asteroid Prospector (RAP). Staged from L1: Start of the Deep Space Economy (2013). Available at: https://www.nasa.gov/sites/default/files/files/Cohen_2012_PhI_RAP.pdf. Accessed 18 May 2017

P. Collier, A. Hoeffler, D. Rohner, *Beyond greed and grievance: feasibility and civil war*. Oxf. Econ. Pap. **61**(1), 1–27 (2009)

K. Cook, *The discovery of lunar water: an opportunity to develop a workable moon treaty*. Georgetown Int. Environ. Law Rev. **11**(3), 647–706 (1999)

A. Crowl, The challenge of relativistic spaceflight (2014). Available at: http://www.icarusinterstellar.org/the-challenge-of-relativistic-spaceflight/. Accessed 8 Mar 2016

S. Cruddas, The truth about asteroid mining: could the untold riches in asteroids and other planets be the key to exploring the wider Universe? (BBC, 2016). Available at: http://www.bbc.com/future/story/20160103-the-truth-about-asteroid-mining. Accessed 18 May 2017

M. Curtis, Mining and tax in South Africa: costs and benefits (2009). Available at: http://curtisresearch.org/wp-content/uploads/SAfrica.MiningTax.Feb09.Curtis.pdf. Accessed 18 May 2017

R. Davies, Mining 'still a key pillar for SA economy' (2015). Available at: https://www.brandsouthafrica.com/south-africa-fast-facts/news-facts/mining-090215#.VvIZqOJ97X4. Accessed 18 May 2017

J. Davis, *The economic effects of windfall gains in export earnings 1975–1978*. World Dev. **11**(2), 119–139 (1983)

S. Davis, Unifying the final frontier: space industry financing reform. Commer. Law J. **106**(4), 455ff (2001)

P.B. De Selding, Luxembourg to invest in space-based asteroid mining (Space News, 2016). Available at: http://spacenews.com/luxembourg-to-invest-in-space-based-asteroid-mining/. Accessed 18 May 2017

Deep Space Industries, U.S. Makes space history: President Obama signs law enabling commercial exploration and use of space resources (2015). Available at: https://deepspaceindustries.com/u-s-makes-space-history/. Accessed 18 May 2017

Deep Space Industries, Prospecting (2016). Available at: https://deepspaceindustries.com/mining/. Accessed 23 May 2017

Deep Space Industries, Who we are (2017). Available at: https://deepspaceindustries.com/business/. Accessed 23 May 2017.

P.S. Dempsey, *National legislation governing commercial space activities*. J. Space Safety Eng. **1**(2), 44–60 (2014)

A. Diekmann, H.P. Richarz, *Future role and significance of space activities in reflection of global social, technological and economic trends*. Acta Astronaut. **45**(11), 697–703 (1999)

EE publishers, Space and beyond (2010). Available at: http://www.ee.co.za/article/space-and-beyond-7.html. Accessed 29 May 2017

M. Endsor, The economics of asteroid mining (2014). Available at: http://www.romeconomics.com/economics-asteroid-mining/. Accessed 23 Mar 2016

S. Ervin, *Law in a vacuum: the common heritage doctrine in outer space law*. Boston College Int. Comp. Law Rev. **7**(2), 403–431 (1984)

Euroconsult, Government Spending in Space Programs at $66.5 Billion in 2014 (2015). Available at: http://www.euroconsult-ec.com/13_May_2015. Accessed 18 May 2017

European Space Agency, Regulations of the European Space Agency: industrial policy rules and regulations (2015). Available at: http://esamultimedia.esa.int/docs/LEX-L/Contracts/ESA_REG_009_Geo_return_coeff_(extranet).pdf. Accessed 18 May 2017

European Space Agency, Law at ESA (2016). Available at: http://www.esa.int/About_Us/Law_at_ESA/Law_at_ESA. Accessed 18 May 2017

European Space Policy Institute, Space policies, issues and trends in 2015–2016 (2016). Available at: http://www.espi.or.at/images/Reports/Rep61_online_161128_1459.pdf. Accessed 26 May 2017

Federal Aviation Administration, Recommended practices for human space flight occupant safety (2014). Available at: https://www.faa.gov/about/office_org/headquarters_offices/ast/media/Recommended_Practices_for_HSF_Occupant_Safety-Version_1-TC14-0037.pdf. Accessed 23 May 2017

J. Foust, Staking a claim to space resources (The Space Review, 2015). Available at: http://www.thespacereview.com/article/2883/1. Accessed 18 May 2017

M. Friedman, *The reduction of fluctuations in the incomes of primary producers: a critical comment*. Econ. J. **64**, 698–703 (1954)

A. Froehlich, *Utilization – consumption – appropriation: asteroid mining is in the pipeline*. ZLW **2**, 268–281 (2017)

R. Gertsch, *Asteroid mining*, in *Space Resources*, ed. by M. F. McKay, D. S. McKay, M. B. Duke (Eds), (Lyndon B. Johnson Space Center, Houston, 1992), pp. 111–120.

R. Gertsch, J.L. Remo, L.S. Gertsch, *Near-earth resources*. Ann. N. Y. Acad. Sci. **822**, 468–510 (1997)

R. Gilpin, *Global Political Economy: Understanding the International Economic Order* (Princeton University Press, Princeton, 2001)

R.H. Goddard, *A Method of Reaching Extreme Altitudes* (The Smithsonian Institution, Washington, DC, 1919)

Government of Canada, Canadian Space Agency Act (n.d.). Available at: http://laws.justice.gc.ca/eng/acts/C-23.2/page-1.html#h-4. Accessed 18 May 2017

Government of China, China's space activities in 2016 (2016). Available at: http://www.scio.gov.cn/zxbd/wz/Document/1537091/1537091.htm. Accessed 22 May 2017

Government of India, The Government of India (Allocation of Business) Rules (1961). Available at: http://cabsec.nic.in/files/allocation/abr_rules_archive_299.pdf. Accessed 19 May 2017

Government of Israel, The Israel Space Agency (2002). Available at: http://most.gov.il/english/space/isa/Pages/default.aspx. Accessed 19 May 2017

Government of Japan, Law concerning the National Space Development Agency of Japan (1969). Available at: http://www.unoosa.org/oosa/en/ourwork/spacelaw/nationalspacelaw/japan/nasda_1969E.html. Accessed 19 May 2017

Government of Luxembourg, Luxembourg to launch framework to support the future use of space resources (2016). Available at: http://www.gouvernement.lu/5653386. Accessed 19 May 2017

Government of Nigeria, National Space Research and Development Agency Act (2010). Available at: http://lawnigeria.com/LawsoftheFederation/NATIONAL-SPACE-RESEARCH-AND-DEVELOPMENT-AGENCY-ACT-2010.html. Accessed 19 May 2017

Government of South Africa, Space Affairs Act of 1993 (1993). Available at: http://www.gov.za/sites/www.gov.za/files/Act84of1993.pdf. Accessed 19 May 2017

Government of South Africa, Space Affairs Amendment Act of 1995 (1995). Available at: http://www.gov.za/sites/www.gov.za/files/Act64of1995.pdf. Accessed 19 May 2017

Government of South Africa, South African National Space Agency Act (2008). Available at: http://www.gov.za/sites/www.gov.za/files/31729_1385_0.pdf. Accessed 19 May 2017

Government of South Africa, South Africa's National Space Policy (2009). Available at: http://africanremotesensing.org/Resources/Documents/Nat_Space_Policy_Doc_A3_pages_final.pdf. Accessed 18 May 2017

Government of South Africa, Mineral Resources. South Africa Yearbook 2014/15 (2014). Available at: http://www.gcis.gov.za/sites/www.gcis.gov.za/files/MineralResources.pdf. Accessed 19 May 2017

Government of the Republic of Korea, Space Development Promotion Act (2005). Available at: http://www.unoosa.org/oosa/en/ourwork/spacelaw/nationalspacelaw/republic_of_korea/space_development_promotions_actE.html. Accessed 19 May 2017

Government of the Russian Federation, Law of the Russian Federation "About Space Activity" (n.d.). Available at: http://www.unoosa.org/oosa/en/ourwork/spacelaw/nationalspacelaw/russian_federation/decree_5663-1_E.html. Accessed 22 May 2017

L. Grush, Elon Musk elaborates on his proposal to nuke Mars (The Verge, 2015). Available at: https://www.theverge.com/2015/10/2/9441029/elon-musk-mars-nuclear-bomb-colbert-interview-explained. Accessed 22 May 2017

R.C. Harding, *Space Policy in Developing Countries: The Search for Security and Development on the Final Frontier* (Routledge, Abingdon, 2013)

S.R. Harminderpal, The "common heritage of mankind" & the final frontier: a revaluation of values constituting the international legal regime for outer space activities. Rutgers Law J. **26**, 225ff (1994)

A.A. Harrison, Living in space, in *Space Sciences, Volume 3: Humans in Space*, ed. by P. Dasch (Ed), (Macmillan Reference USA, New York, 2002), pp. 119–122.

B. Herber, *Mining or world park? A politico-economic analysis of alternative land use regimes in Antarctica*. Nat. Resour. J. **31**(4), 839–857 (1991)

T. Hlimi, *The next frontier: an overview of the legal and environmental implications of near-earth asteroid mining*. Annals Air Space Law **39**, 409–453 (2015)

IBT times, Nigeria's Space Program: A Rare Glimpse Inside The West African Nation's Satellite Operation (2013). Available at: http://www.ibtimes.com/nigerias-space-program-rare-glimpse-inside-west-african-nations-satellite-operation-1411236. Accessed 29 May 2017

T.A. Imobighe, Conflict in Niger Delta: a unique case or a 'model' for future conflicts in other oil-producing countries? in *Oil Policy in the Gulf of Guinea*, ed. by R. Traub-Merz, D. Yates (Eds), (Friedrich-Ebert-Stiftung, Johannesburg, 2016), pp. 101–115

Indian Space Research Organisation, Genesis (2016). Available at: http://www.isro.gov.in/about-isro/genesis. Accessed 19 May 2017

International Association for the Advancement of Space Safety, Welcome to IAASS (2016). Available at: http://iaass.space-safety.org. Accessed 19 May 2017

International Atomic Energy Agency, Statute (1989). Available at: https://www.iaea.org/sites/default/files/statute.pdf. Accessed 22 May 2017

International Bank for Reconstruction and Development. (1945). *Articles of Agreement of the International Bank for Reconstruction and Development*. New York: United Nations.

International Council for Science, Space Research (COSPAR) (n.d.). Available at: http://www.icsu.org/what-we-do/interdisciplinary-bodies/cospar. Accessed Mar 2016

International Organization for Standardization, ISO 14620-2:2011: Space systems – Safety requirements – Part 2: Launch site operations (n.d.). Available at: https://www.iso.org/standard/46182.html. Accessed 19 May 2017

International Space University Space Studies Program, ASTRA: ASteroid mining, technologies roadmap and applications, Final Report, International Space University, Strasbourg (2010)

INTOSAI Working Group on Environmental Auditing, INTOSAI WGEA Work Plan (2010). Available at: http://www.environmental-auditing.org/Home/WGEAActivities/WorkPlans/tabid/112/Default.aspx. Accessed 19 May 2017

InvestmentMine, Platinum investing – platinum stocks, mining companies, prices and news (2016a). Available at: http://www.infomine.com/investment/platinum/. Accessed 16 Mar 2016

InvestmentMine, Spot platinum price and platinum price chart (2016b). Available at: http://www.infomine.com/investment/metal-prices/platinum/1-day-spot/. Accessed 16 Mar 2016

C. Jamasmie, Russia pushes forward plans to mine the moon (2014). Available at: http://www.mining.com/russia-pushes-forward-plans-to-mine-the-moon-13769/. Accessed 19 May 2017

K. Katkin, *Communication breakdown? The future of global connectivity after the privatisation of INTELSAT*. Vanderbilt J. Transl. Law **38**(5), 1323–1402 (2005)

Keck Institute for Space Studies, Asteroid retrieval feasibility study (2012,). Available at: http://www.kiss.caltech.edu/study/asteroid/asteroid_final_report.pdf. Accessed 19 May 2017

D.H. Kim, Space Law and Policy in the Republic of Korea (2010). Available at: http://www.unoosa.org/pdf/pres/2010/SLW2010/02-09.pdf. Accessed 19 May 2017

H. King, REE – rare earth elements and their uses (2016). Available at: http://geology.com/articles/rare-earth-elements/. Accessed 19 May 2017

V. Kopal, *The role of united nations declarations of principles in the progressive development of space law*. J. Space Law **16**(1), 5–20 (1988)

K. Kumar, Sorry, but this plan to mine asteroids is a big load of junk (Business Insider, 2012a). Available at: http://www.businessinsider.com/planetary-resources-seeks-to-mine-asteroids-but-skeptics-say-plan-amounts-to-hot-air-2012-5. Accessed 22 May 2017

A. Kumar, Feasibility studies (2012b). Available at: http://technology.infomine.com/reviews/FeasibilityStudies/welcome.asp?view=full. Accessed 31 May 2017

R. Lee, *Law and Regulation of Commercial Mining of Minerals in Outer Space* (Springer, The Hague, 2012)

A. Lele, India's space program looks outwards, (The Space Review, 2015). Available at: http://www.thespacereview.com/article/2836/1. Accessed 19 May 2017

J.S. Lewis, Logistical implications of water extraction from near-earth asteroids. Princeton conference on space manufacturing. (Space Studies Institute, Mojave, 1993)

J.S. Lewis, *Mining the Sky: Untold Riches from the Asteroids, Comets, And Planets* (Helix Books, New York, 1996)

J. Lind, Ecological sources of conflicts in Sun-Saharan. ACTS, (2001)

M. Listner, 2003, *The ownership and exploitation of outer space: a look at foundational law and future legal challenges to current claims*, Regent J. Int. Law

M. Listner, *The Moon Treaty: failed international law or waiting in the shadows*? (The Space Review, 2011). Available at: http://www.thespacereview.com/article/1954/1. Accessed 19 May 2017

M.-K. Looi, World risks 'scientific apartheid', says top African scientist (2008). Available at: http://www.scidev.net/global/policy/news/world-risks-scientific-apartheid-says-top-african-.html. Accessed 23 May 2017

L.D. Lopez, *Regional Space Cooperation: Spotlight on Latin America* (Space & Society Course, University of Cape Town, Cape Town, 2016)

Y. Marshall, *Introduction to space safety*, in *Safety Design for Space Systems*, ed. by G. E. Musgrave, A. M. Larsen, T. Sgobba (Eds), (Elsevier Ltd, Oxford, 2009).

P. Martinez, Role of COPUOS in promoting sustainability of outer space activities, UNIDIR Space Security Conference, Geneva, (2013)

P. Martinez, *Africa in Space* (Space and Society Course, University of Cape Town, Cape Town, 2016)

K. Maslar, *The Concept of the Common Heritage of Mankind in International Law* (Brill, Leiden, 1998)

T. Masson-Zwaan, *Space Law and the Use of Space Resources Guest lecture for University of Cape Town* (Space & Society Course, University of Cape Town, Cape Town, 2016)

G.L. Matloff, M. Wilga, *NEOs as stepping stones to Mars and main-belt asteroids*. Acta Astronaut. **68**(5-6), 599–602 (2011)

D. Messier, House Democrats Slam SPACE Act as 'Commercial Space Industry Wish List' (Parabolic Arc, 2015a). Available at: http://www.parabolicarc.com/2015/05/21/house-democrats-slam-space-act-commercial-space-industry-list/. Accessed 19 May 2017

D. Messier, UAE Space Agency to Unveil Strategy, Operational Plan on Monday (Parabolic Arc, 2015b). Available at: http://www.parabolicarc.com/2015/05/24/uae-space-agency-unveil-strategy-operational-plan-monday/. Accessed 19 May 2017

Z. Meyer, *Private commercialization of space in an international regime: a proposal for a space district*. North. J. Int. Law Bus. **30**(1), 241–261 (2010)

Mission 2016: The Future of Strategic Natural Resources, Asteroid mining. A possible new future alternative to land mining (n.d.). Available at: http://web.mit.edu/12.000/www/m2016/finalwebsite/solutions/asteroids.html. Accessed 19 May 2017

S.M. Molema, *The Bantu, Past and Present; An Ethnographical & Historical Study of the Native Races of South Africa* (W. Green & Son Limited, Edinburgh, 1920)

R. Nagappa, Space Policy and Law of India (n.d.). Available at: http://swfound.org/media/41406/6.%20pres%20swf-cas%20space%20laws%20and%20policies%20workshop%20-%20rajaram%20nagappa%20-%20space%20policy%20and%20law%20of%20india.pdf. Accessed 19 May 2017

L. Napier, S. Hettrich, Interplanetary contamination and extraterrestrial life (Space Safety Magazine, 2014. Available at: http://www.spacesafetymagazine.com/space-exploration/extra-terrestrial-life/. Accessed 19 May 2017
NASA Jet Propulsion Laboratory, Images of Eros (2016). Available at: http://photojournal.jpl.nasa.gov/target/Eros?start=0. Accessed 19 May 2017
NASA Jet Propulsion Laboratory, Mission to Jupiter (Galileo, n.d.-a). Available at: http://www.jpl.nasa.gov/missions/galileo/. Accessed 19 May 2017
NASA Jet Propulsion Laboratory, Missions (n.d.-b). Available at: http://www.jpl.nasa.gov/missions/. Accessed 22 May 2017
National Aeronautics and Space Administration, What is NASA's Asteroid Redirect Mission? (n.d.-a). Available at: https://www.nasa.gov/content/what-is-nasa-s-asteroid-redirect-mission/. Accessed 19 May 2017
National Aeronautics and Space Administration, Deep impact. Mission to a Comet (n.d.-b). Available at: http://www.nasa.gov/mission_pages/deepimpact/main/#.Vue0BpN97Vo. Accessed 19 May 2017
National Aeronautics and Space Administration, HAYABUSA (n.d.-c). Available at: https://solarsystem.nasa.gov/missions/muses. Accessed 19 May 2017
National Archives, Space exploration (n.d.). Available at: http://www.archives.gov/research/alic/reference/space-timeline.html. Accessed 19 May 2017
National Research Council, Vision and voyagers for planetary science in the decade 2013–2022 (2011). Available at: http://solarsystem.nasa.gov/2013decadal. Accessed 19 May 2017
T. Nelson, The moon agreement and private enterprise: lessons from investment law, ILSA. J. Int. Comp. Law 17(2), 393–416 (2011)
New Space India, Excerpts of the 'Round Table Conference on Issues for National Space Legislation' (n.d.). Available at: http://www.newspaceindia.com/excerpts-of-round-table-conference-on-issues-for-national-space-legislation/. Accessed 19 May 2017
I. O'Neill, Asteroid Mining: Booming 21st Century Gold Rush? (n.d.). Available at: http://news.discovery.com/space/asteroids-meteors-meteorites/could-asteroid-mining-drive-21st-century-space-industry-130204.htm. Accessed 19 May 2017
A.Y. Ol'khovatov, *Geographical circumstances of the 1908 Tunguska Event in Siberia, Russia*. Earth Moon Planet. 93(3), 163–173 (2003)
C.D. Oliver, *Interim deep seabed mining legislation: an international environmental perspective*. J. Legis. **8**(1), 73–103 (1981)
S. Onuh, The growth and development of the Nigerian Space Programme (2012). Available at: http://www.suparco.gov.pk/downloadables/nsc2.pdf. Accessed 19 May 2017
J. Orwig, *A tiny European country just made an unprecedented move in the space mining business* (Business Insider, 2016). Available at: http://www.businessinsider.com/luxembourg-wants-to-cash-in-on-asteroid-mining-2016-2. Accessed 19 May 2017
A. Panzar, *A methodology for measuring the costs of universal service obligations*. Inf. Econ. Policy **12**(3), 211–220 (2000)
X. Pasco, *A European Approach to Space Security* (American Academy of Arts and Sciences, New York, 2009)
J. Pearsall, *Concise Oxford Dictionary* (University Press, London, 1999)
J.N. Pelton, R.S. Jakhu, Introduction to space safety regulations and standards, in *Space Safety Regulations and Standards*, ed. by J. N. Pelton, R. S. Jakhu (Eds), (Butterworth-Heinemann, Oxford, 2010), pp. xli–xliv.
M.B. Pepys, *Role of complement in induction of the allergic response*. Nat. New Biol. **237**(74), 157–159 (1972)
Planetary Resources, President Obama signs Bill Recognizing Asteroid Resource Property Rights Into Law (2015,). Available at: http://www.planetaryresources.com/2015/11/president-obama-signs-bill-recognizing-asteroid-resource-property-rights-into-law/. Accessed 19 May 2017
Planetary Resources, Asteroid composition (n.d.). Available at: http://www.planetaryresources.com/asteroids/#asteroids-types-of-asteroids. Accessed 23 May 2017

O.P. Popova et al., *Chelyabinsk airburst, damage assessment, meteorite recovery, and characterization*. Science **342**(6162), 1069–1073 (2013)

G.C. Raclin, *From ice to ether: the adoption of a regime to govern resource exploitation in outer space*. North. J. Int. Law Bus. **7**(4), 727–761 (1986)

H.E. Roland, B. Moriarty, *System Safety Engineering and Management* (Wiley, New York, 1990)

I. Romanova, *Oil Boom in Nigeria and Its Consequences for the Country s Economic Development* (University of Paderborn, Paderborn, 2007)

Roscosmos, Activities (2016). Available at: http://en.federalspace.ru/20269/. Accessed 19 May 2017

E. Rosenfeld, Russian firm proposes $9.4B moon base for mining (CNBC, 2015). Available at: http://www.cnbc.com/2015/01/02/russian-firm-proposes-94b-moon-base-for-mining.html. Accessed 19 May 2017

S.D. Ross, Near-earth asteroid mining (2001). Available at: http://www2.esm.vt.edu/~sdross/papers/ross-asteroid-mining-2001.pdf. Accessed 19 May 2017

M. Ross, M. Mills, D. Toohey, *Potential climate impact of black carbon emitted by rockets*. Geophys. Res. Lett. **37**(24), 1–6 (2010)

R.L. Schweickart, The real deflection dilemma, Planetary Defense Conference: Protecting Earth from Asteroids, California, 23–26 February, (2004)

Secretariat of the Antarctic Treaty, The Antarctic Treaty (1959). Available at: http://www.ats.aq/documents/ats/treaty_original.pdf. Accessed 22 May 2017

T. Sgobba, International Space Safety Space Standard. TRISMAC Conference 14–16 April 2008.

T. Sgobba, P.D. Wilde, I. Rongier, F.A. Allahdadi, Introduction to space operations safety, in *Safety Design for Space Operations*, ed. by F. Allahdadi, I. Rongier, P. Wilde (Eds), (Elsevier Ltd, Oxford, 2013)

R. Sharma, Deep-Sea mining: economic, technical, technological, and environmental considerations for sustainable development. Mar. Technol. Soc. J. **45**(5), 28–41 (2011)

T. Simmons, The unfortunate provincialism of the space resources act (The Space Review, 2016). Available at: http://www.thespacereview.com/article/2910/1. Accessed 22 May 2017

M. Smith, Space law activities (2015). Available at: http://www.spacepolicyonline.com/space-law. Accessed 22 May 2017

M. Sonter, The Technical and Economic Feasibility of Mining the Near-Earth Asteroids, MSc thesis, Dept. of Physics and Dept. of Civil and Mining Engineering, University of Wollongong, (1996)

M. Sonter, Asteroid mining: key to the space economy (2006). Available at: http://spsaero.us/Key_ComSpace_Articles/LibGen/LIB-077_Asteroid_Mining-Key_to_the_Space_Economy.pdf. Accessed 22 May 2017

South African Civil Aviation Authority, SACAA Mandate (2016). Available at: http://www.caa.co.za/Pages/About%20Us/SACAA-Mandate.aspx. Accessed 26 May 2017

South African Council for Space Affairs, National Registry of Objects Launched into Outer Space (2013). Available at: http://www.sacsa.gov.za/registry/index.php. Accessed 26 May 2017

South African History Online, The South African War 1899-1902 (2016). Available at: http://www.sahistory.org.za/topic/south-african-war-1899-1902. Accessed 22 May 2017

Space Daily, Orbdev Files Federal Suit Over Asteroid 433 Eros Claim (2003). Available at: http://www.spacedaily.com/news/oped-03zzw.html. Accessed 19 May 2017

Statistics South Africa, National Accounts: Mineral Accounts for South Africa: 1980 – 2009 (2012). Available at: http://www.statssa.gov.za/publications/D04052/D040522009.pdf. Accessed 22 May 2017

Statistics South Africa, Economic growth (2016). Available at: http://www.statssa.gov.za/?page_id=735&id=1. Accessed 22 May 2017

Statistics Times, Projected GDP Ranking (2016–2020) (2016). Available at: http://statisticstimes.com/economy/projected-world-gdp-ranking.php. Accessed 22 May 2017

K. Suzuki, *Asia in Space, Space & Society Course* (University of Cape Town, Cape Town, Cape Town, 2016)

M.V. Syckes, Science and exploration of small bodies in the solar system (2011). Available at: http://www.lpi.usra.edu/sbag/meetings/jan2011/presentations/day1/d1_0950_exploration_sykes.pdf. Accessed 22 May 2017

R. Tangum, *Future space development scenarios: environmental considerations*, in *Space Resources: Social Concerns*, ed. by M. F. McKay, D. S. McKay, M. B. Duke (Eds), (NASA, Washington, DC, 1992), pp. 220–230.

J.G. Teicher, The human cost of South Africa's Mining Industry (2014). Available at: http://www.slate.com/blogs/behold/2014/09/09/ilan_godfrey_documents_the_impact_of_south_africa_s_mining_industry_in_his.html. Accessed 22 May 2017

Telecompaper, Angosat 1 satellite to launch in Q3 (2017). Available at: https://www.telecompaper.com/news/angosat-1-satellite-to-launch-in-q3--1182558. Accessed 29 May 2017

The Economic Times, After US, China plans 'Deep Impact' mission (2005). Available at: http://archive.li/9E2QY. Accessed 22 May 2017

The Economist, The paradox of plenty (2005). Available at: http://www.economist.com/node/5323394. Accessed 22 May 2017

The Mars Society, Asteroid mining (n.d.). Available at: http://chapters.marssociety.org/winnipeg/asteroid.html. Accessed 22 May 2017

The Richest, The 10 nations that spend the most on space exploration (2014). Available at: http://www.therichest.com/rich-list/world/the-10-nations-that-spend-the-most-on-space-exploration/. Accessed 22 May 2017

The Tauri Group, The South African Space industry (2011). Available at: http://www.spacesa.org/resources/South_Africa_Space_Industry2011.pdf. Accessed 29 May 2017

U.S. Congress, H.R.2262 – U.S. Commercial Space Launch Competitiveness Act (2015). Available at: https://www.congress.gov/bill/114th-congress/house-bill/2262/text. Accessed 18 May 2017

UAE Space Agency, Space policies and regulations (2015,). Available at: http://www.space.gov.ae/space-policies-and-regulations. Accessed 22 May 2017

United Nations. (1963). *Declaration of Legal Principles Governing the Activities of States in the Exploration and Use of Outer Space*. New York: United Nations.

United Nations. (1967). *Treaty on Principles Governing the Activities of States in the Exploration and use of Outer Space, Including the Moon and Other Celestial Bodies*. New York: United Nations.

United Nations. (1970). *Declaration of Principles Governing the Sea-Bed and the Ocean Floor, and the Subsoil Thereof, Beyond the Limits of National Jurisdiction*. New York: United Nations.

United Nations. (1972). *Convention on International Liability for Damage Caused by Space Objects*. New York: United Nations.

United Nations. (1977). *Agreement Establishing the International Fund for Agricultural Development*. New York: United Nations.

United Nations. (1979). *Agreement Governing the Activities of States on the Moon and Other Celestial Bodies*. New York: United Nations.

United Nations. (1986). *Principles Relating to Remote Sensing of the Earth from Space*. New York: United Nations.

United Nations. (1996). *Declaration on International Cooperation in the Exploration and use of Outer Space for the Benefit and in the Interest of All States, Taking into Account Needs of Developing Countries*. New York: United Nations.

United Nations. (2013). *Recommendations on National Legislation Relevant to the Peaceful Exploration and Use of Outer Space*. New York: United Nations.

United Nations Committee on the Peaceful Uses of Outer Space. (2006). *Report on the United Nations/Nigeria Workshop on Space Law on the theme "Meeting international Obligations and Addressing Domestic Needs"*. Abuja: United Nations.

United Nations Committee on the Peaceful Uses of Outer Space. (2014). *Schematic Overview of National Regulatory Frameworks for Space Activities*. Vienna: United Nations.

United Nations Committee on the Peaceful Uses of Outer Space. (2016). *National Legislation and Practice Relating to the Definition and Delimitation of Outer Space: Algeria*. Vienna: United Nations.

United Nations Committee on the Peaceful Uses of Outer Space. (2017). *Status of International Agreements Relating to Activities in Outer Space as at 1 January 2017*. Vienna: United Nations.

United Nations Economic Commission for Africa. (2004). *Harmonization of Mining Policies, Standards, Legislative and Regulatory Frameworks in Southern Africa*. Addis Ababa: United Nations.

United Nations Institute for Disarmament Research, A brief overview of norms development in outer space (2013). Available at: http://www.unidir.org/files/publications/pdfs/a-brief-overview-of-norms-development-in-outer-space-en-462.pdf. Accessed 22 May 2017

United Nations Office for Outer Space Affairs, United nations treaties and principles on outer space and related general assembly resolutions (2008). Available at: http://www.unoosa.org/res/oosadoc/data/documents/2008/stspace/stspace11rev_2_0_html/st_space_11rev2E.pdf. Accessed 22 May 2017

United Nations Office of the High Representative for the Least Developed Countries, Landlocked Developing Countries and Small Island Developing States, Criteria for identification and graduation of LDCs (2016). Available at: http://unohrlls.org/about-ldcs/criteria-for-ldcs/. Accessed 22 May 2017

A.J. Van Vuuren, The world's third-biggest platinum miner just announced that it's cutting production, (Bloomberg, 2015). Available at: http://www.bloomberg.com/news/articles/2015-07-24/the-world-s-third-biggest-platinum-miner-just-announced-that-it-s-cutting-production. Accessed 22 May 2017

A.J. Venables, *Using natural resources for development: why has it proven so difficult?* J. Econ. Perspect. **30**(1), 161–184 (2016)

M. Wall, Asteroid-mining project aims for deep-space colonies. (2013). Available at: http://www.space.com/19368-asteroid-mining-deep-space-industries.html. Accessed 22 May 2017

Wassenaar Arrangement Secretariat, The Wassenaar Arrangement On Export Controls for Conventional Arms and Dual-Use Goods and Technologies (2009). Available at: http://www.wassenaar.org/. Accessed 22 May 2017

F. Wilson, *Minerals and migrants: how the mining industry has shaped South Africa*. Daedalus **130**(1), 99–121 (2001)

J. Wilson, What Is NASA's Asteroid Redirect Mission? (2015). Available at: https://www.nasa.gov/content/what-is-nasa-s-asteroid-redirect-mission. Accessed 22 May 2017

R. Wolfrum, *The principle of the common heritage of mankind*. Heidelberg J. Int. Law **43**(2), 312–337 (1983)

World Trade Organization, Agreement establishing the world trade organization (1994). Available at: https://www.wto.org/english/docs_e/legal_e/04-wto.pdf. Accessed 22 May 2017